

**MANAGEMENT OF CERVICAL BIOMECHANICAL
DYSFUNCTION IN SCHOOLBOY RUGBY PLAYERS
USING A MANUAL PHYSIOTHERAPY TECHNIQUE.**

**LINDA STEYN
MPhysT (OMT)**

**Thesis Submitted for the degree Philosophiae Doctor in
Educational Science (Movement Science Education) at
North-West University**

**Promoter: Prof. E.J. Spamer
Assistant Promoter: Dr. D.C. Janse van Rensburg**

2005

Potchefstroom

This study is dedicated

to

LEON

and

JEAN-PIERRÉ

*Real happiness is not dependant on external things,
the pond is fed from within. The kind of happiness that
stays with you is the happiness that springs from inward
thoughts and emotions. You must think of this now, while are young.
You must cultivate your mind if you wish to achieve enduring
happiness.*

*You must furnish your mind with interesting
thoughts and ideas. For an empty mind grows bored and
cannot endure itself. An empty mind seeks pleasure as a substitute for
happiness.*

William Lyon Phelps

Watson, L.E., Lights from many lamps.
Simon & Schuster, New York

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and appreciation to:

- Prof. E.J. Spamer, my promoter for his time, commitment, and valuable input during the course of this study.
- My assistant promoter, Dr. D.C. Janse van Rensburg, for her input and help during the course of this study.
- Prof. Kosie van Wyk for motivation, inspiration and technical assistance with the study.
- Mrs. Masha Eisenberg, supervisor for my Masters degree, for assisting with editing this thesis and continued professional advice.
- The radiologists and radiographers of Burger and Partners Inc., for making available their facilities and for their financial support. A special word of thanks to Drs de Beer and Heyneke, Brenda Corbet and Clive.
- The South African Society of Physiotherapy for their financial contribution.
- My colleagues; Jeanette van der Walt, Julian Cloete, Kerushar Moodley, Martelize Kok, Viola van der Walt and Yolandé de Jager, for professional and technical support.
- Hestie Krüger, for assisting with logistical arrangement.
- For all the staff at my practice for their patience and moral support.
- Mr. Chris Venter for his effort with the implementation of the programmes at Kempton Park Hoërskool.
- Mr Hans van den Vreden at Dr. E.G. Jansen Hoërskool for his effort with the implementation of the programmes.
- Mr. Chris Botha, for assistance at Birchleigh Hoërskool.

- Prof. H.S. Steyn the study design and statistical analysis of the data.
- My children and parents for being so patient and understanding.
- Bestie van Wyk for her continued hospitality and support.
- Mr. Mark Cloete for being the model for the programme photographs.

ABSTRACT

Aims: The primary physiotherapeutic aims of the study were to validate a manual physiotherapy evaluation technique in the assessment of cervical biomechanical dysfunction, and to test the effectiveness of a manual physiotherapy treatment technique in the correction of cervical biomechanical dysfunction. The primary educational aims were to test the effectiveness and safety of a therapeutic exercise programme for the correction of biomechanical dysfunction as well as the effectiveness of a neck rehabilitation programme for improving neck muscle strength.

Design: A four group experimental design with three pre-test - post-test groups and a control group was used for the investigation.

Sample: The subjects were South African schoolboy rugby players between the ages of 15 and 18 years. Groups 1 and 2 presented with biomechanical dysfunction of their cervical spines, Group 3 had no biomechanical dysfunction of their cervical spines and the players of Group 4, the control group, presented with or without biomechanical dysfunction of their cervical spines. Each group consisted of 25 players.

Method: Group 1 received manual physiotherapy with x-rays before and after treatment. Groups 2 and 3 performed a therapeutic exercise programme, with before and after x-rays, and Group 4 received no intervention between their sets of x-rays. Following the second set of x-rays all the players from Groups 1, 2 and 3 performed the neck rehabilitation programme after which a third set of x-rays were taken.

Results: The results validated the manual physiotherapy evaluation technique. The manual therapy treatment technique used in the treatment of Group 1 showed highly significant improvements in cervical biomechanical function. Results for Group 2 following the therapeutic exercise programme showed moderate practically significant improvements in cervical biomechanical dysfunction. The therapeutic exercise programme for the correction of biomechanical dysfunction was found to be

very safe with only small significant changes in x-ray measurements (Group 3). The results of the control group showed a negative trend of small statistical significance. A highly significant improvement in cervical circumference as moderate significant improvement in biomechanical function was found following the neck rehabilitation programme.

Conclusion: It could therefore be concluded that the manual physiotherapy evaluation technique for motion segment analysis was indeed valid in determining biomechanical dysfunction of the cervical spine. The manual physiotherapy treatment technique as well as the therapeutic exercise programme for the correction of biomechanical dysfunction was found to be effective in the correction of cervical biomechanical dysfunction. It could further be concluded that the therapeutic exercise programme was safe to be performed by players without biomechanical dysfunction. The neck rehabilitation programme was effective in improving cervical circumference as well as cervical biomechanical function.

Keywords:

- Cervical Spine
- Biomechanical Dysfunction
- Schoolboy Rugby Players
- Manual Therapy
- Physiotherapy

OPSOMMING

Doelwit: Die primêre fisioterapeutiese doelwitte van die studie was om die manuele fisioterapeutiese evalueringstegniek te valideer in die assessering van servikale biomeganiese disfunksie en om die effektiwiteit van die manuele fisioterapeutiese behandelingstegniek te bepaal in die herstel van biomeganiese disfunksie. Die primêre opvoedings doelwitte was om die effektiwiteit en veiligheid van die terapeutiese oefenprogram vir die herstel van biomeganiese disfunksie te bepaal. 'n Verdere doelwit was om die effektiwiteit van die nek rehabilitasieprogram vir toename in nekspierkrag te bepaal.

Ontwerp: 'n Viergroep eksperimentele ontwerp met drie pre-toets, post-toetsgroepe en 'n kontrole groep.

Studiepopulasie: Suid-Afrikaanse skoolseun rugbyspelers, tussen die ouderdomme van 15 en 18 jaar. Groep 1 en 2 het gepresenteer met servikale biomeganiese disfunksie. Groep 3 het nie servikale biomeganiese disfunksie getoon nie en Groep 4 het spelers met of sonder servikale biomeganiese disfunksie ingesluit. Elke groep het bestaan uit 25 spelers.

Metode: Groep 1 het manuele fisioterapie behandeling ontvang met x-strale voor en na die behandeling. Groep 2 en 3 het 'n terapeutiese oefenprogram vir die herstel van servikale biomeganiese disfunksie gevolg met x-strale voor en na die program. Groep 4 het geen intervensie tussen die twee stelle x-strale ontvang nie. Na die tweede stel x-strale het al die spelers van Groepe 1, 2 en 3 'n nek rehabilitasie program gevolg vir 12 weke, waarna 'n derde stel x-strale geneem is.

Resultate: Die resultate het die manuele fisioterapeutiese evalueringstegniek gevalideer. Verder het resultate van Groep 1 gewys dat die manuele fisioterapeutiese behandelingstegniek hoogs betekenisvolle verbeterings in servikale biomeganiese funksie getoon het. Die resultate van Groep 2 het matige verbeterings in servikale biomeganiese funksie na die terapeutiese oefenprogram getoon. Die resultate van Groep 3 het gewys dat die terapeutiese oefenprogram veilig is wanneer dit deur

spelers sonder servikale biomeganiese disfunksie gevolg word, met slegs klein veranderings in x-straal metings. Die resultate vir die kontrolegroep het 'n klein betekenisvolle negatiewe tendens in x-straal metings getoon. 'n Hoog betekenisvolle verbetering in nekomtrek en 'n matig betekenisvolle verbetering in servikale biomeganiese funksie is gevind in die spelers wat die nek rehabilitasie program voltooi het.

Gevolgtrekking: Die gevolgtrekking kan dus gemaak word dat die manuele fisioterapeutiese evalueringstegniek effektief is om servikale biomeganiese disfunksie te bepaal. Verder is gevind dat die manuele fisioterapeutiese behandelingstegniek effektief is in die herstel van servikale biomeganiese disfunksie. Dit is gewys dat die terapeutiese oefenprogram effektief is vir die herstel van servikale biomeganiese disfunksie en veilig is om te voltooi vir spelers sonder servikale biomeganiese disfunksie. Die nek rehabilitasie program is doeltreffend om nekomtrek asook servikale biomeganiese funksie te verbeter.

Sleutelwoorde:

- Servikaal werwelkolom
- Biomeganiese Disfunksie
- Skoolseun Rugbyspelers
- Manuele Terapie
- Fisioterapie

TABLE OF CONTENTS

DEDICATION	i
ACKNOWLEDGEMENTS	ii
ABSTRACT	iv
OPSOMMING	vi
TABLE OF CONTENTS	viii
LIST OF TABLES	xix
LIST OF FIGURES	xxiv

CHAPTER 1: PERSPECTIVES AND PROBLEM STATEMENT-1

1.1	INTRODUCTION	1
1.2	RUGBY	2
1.3	PHYSIOTHERAPY IN BIOMECHANICS	3
1.4	MOTION SEGMENT ANALYSIS	4
1.5	BIOMECHANICAL DYSFUNCTION FOUND IN SCHOOLBOY RUGBY PLAYERS	5
1.6	MANUAL PHYSIOTHERAPY FOR THE CORRECTION OF BIOMECHANICAL DYSFUNCTION	7
1.7	EARLY DEGENERATION	7
1.8	CERVICAL SPINE INJURIES	9
1.9	RESEARCH QUESTION	11
1.10	AIMS AND OBJECTIVES	11
1.10.1	Primary Physiotherapeutic Aims	11
1.10.2	Primary Education Aims	11
1.10.3	Secondary Aims	11

1.11	METHODOLOGY	12
1.11.1	Literature review	12
1.11.2	Empirical Investigation	12
1.11.2.1	Study Design	12
1.11.2.2	Population and Sample	13
1.11.2.3	Measurements and Instruments	13
1.11.2.4	Procedure	13
1.11.2.5	Statistical Analysis	14
1.12	RELEVANCE OF THE STUDY	14
1.13	OPERATIONAL TERMS	15
1.14	SUMMARY	17
 CHAPTER 2: LITERATURE REVIEW-----		18
2.1	AIM OF THE LITERATURE REVIEW CHAPTERS	18
2.2	METHODOLOGY OF THE LITERATURE REVIEW	18
2.3	INTRODUCTION TO THE LITERATURE REVIEW	19
2.4	YOUNG PEOPLE AND PHYSICAL ACTIVITY	20
2.4.1	Schoolboy Rugby Players and the game of Rugby	21
2.5	RUGBY	22
2.5.1	Brief History of Rugby	22
2.5.2	Rugby Injuries	22
5.2.2.1	Intrinsic Factors in Rugby Injuries	23
5.2.2.2	Extrinsic Factors in rugby injuries	24
2.6	ROLE PLAYERS IN THE MANAGEMENT OF THE SCHOOLBOY RUGBY PLAYER	25
2.6.1	Physiotherapy and other healthcare professionals	25
2.6.2	Coach and other educators	26
2.7.	SUMMARY	27

CHAPTER 3: ANATOMY AND BIOMECHANICS

LITERATURE REVIEW	28
3.1 ANATOMY	28
3.1.1 Types of Tissue	28
3.1.1.1 Skeletal Muscle	29
3.1.1.2 Bone	32
3.1.1.3 Cartilage	33
3.1.1.4 Tendons and Ligaments	34
3.1.1.5 Fascia	35
3.1.2. Arthrology	35
3.2 BIOMECHANICS	36
3.2.1. Biomechanical Terms	38
3.2.1.1 Mass and Inertia	39
3.2.1.2 Force	39
3.2.1.3 Moment of Force	40
3.2.1.4 Collisions	40
3.2.1.5 Friction	41
3.2.1.6 Fluid Mechanics	41
3.2.1.7 Joint Mechanics	41
3.2.1.8 Lever Systems	42
3.2.1.9 Joint Lubrication	42
3.2.1.10 Rigid-body Mechanics	43
3.2.2. Biomechanics of the Spine	44
3.2.2.1 The Vertebra	46
3.2.2.2 The Intervertebral Disc	48
3.2.2.3 Spinal Ligaments	58
3.2.2.4 Spinal Cord	62
3.2.2.5 Muscles	63
3.2.2.6 The Zygapophyseal Joints	64
3.3 SUMMARY	66

CHAPTER 4: LITERATURE REVIEW ON HUMAN MOVEMENT	67
4.1 INTRODUCTION TO HUMAN MOVEMENT	67
4.2 TERMINOLOGY USED IN THE DESCRIPTION OF HUMAN MOVEMENT	68
4.2.1 Unit vectors	68
4.2.2 Degrees of Freedom	68
4.2.3 Axis of Rotation	69
4.2.4 Coordinate System to describe Motion	69
4.3 SEGMENTAL MOTION OF THE CERVICAL SPINE	70
4.3.1 Motion Segment	71
4.3.2 Flexibility and Neutral Zone	72
4.3.3 Three Dimensional Motion	72
4.3.4 Zygapophyseal joints of the cervical spine in Motion Segment Analysis	72
4.3.5 Flexion and Extension of the Cervical Spine	75
4.3.6 Combined Rotation and Lateral Bending	76
4.3.7 X-ray Measurements of Segmental Motion	77
4.3.7.1 Flexion and Extension Angles between vertebrae	80
4.3.7.2 Angles of Rotation	81
4.3.7.3 Translation	81
4.3.7.4 Axis of Rotation	82
4.4 MANUAL PHYSIOTHERAPY EVALUATION OF SEGMENTAL MOTION	82
4.5 MANUAL PHYSIOTHERAPY TREATMENT FOR THE CORRECTION OF CERVICAL SPINE BIOMECHANICAL DYSFUNCTION	85

4.6	DEVELOPMENT OF A THERAPEUTIC EXERCISES PROGRAMME FOR THE CORRECTION OF CERVICAL BIOMECHANICAL DYSFUNCTION.	86
4.7	DEGENERATIVE CHANGES OF THE CERVICAL SPINE	87
4.8	DEVELOPMENT OF A NECK REHABILITATION PROGRAMME	88
4.8.1	Introduction	89
4.8.2	Neuroscience	91
4.8.3	Motor learning	92
4.8.3.1	The Intake of Sensory Information	92
4.8.3.2	Internal Neural Coding	97
4.8.3.3	Memory	99
4.8.3.4	Motor Response	101
4.8.3.5	Functional Localizing and Sensory-Motor Transformations	103
4.8.3.6	Central Pattern Generation	103
4.8.3.7	The Role of the Cerebellum and Basal Ganglia in Motor Learning and Cognition	104
4.8.3.8	Skilled-Learning-Induced Potentiation in Rat Sensory-Motor Cortex	105
4.8.4	Neuromuscular Control	106
4.8.4.1.	Models for Neuromuscular Control	108
4.8.4.2.	Internal Models and Neuromuscular Control	109
4.8.4.3	Feedforward and Feedback Neuromuscular Control	110
4.8.4.4	Limitations of motor control	111
4.8.5	The Neck Rehabilitation Programme	112
4.8.5.1	General Principles for Neck Rehabilitation Programme	113
4.8.5.2	Strength Training	117
4.8.5.3	Re-establishing Neuromuscular Control	127
4.8.5.4	Closed Kinetic Chain Exercises	128
4.8.5.5	Proprioceptive Neuromuscular Facilitation (PNF)	128
4.8.5.6	Stretch shortening activities	130
4.8.5.7	Reactive Neuromuscular Control	130

4.8.5.8	Plyometrics	131
4.8.5.9	Sport Specific Training	132
4.8.5.10	Skill	133
4.8.5.11	Muscles focused on for the Neck Rehabilitation Programme	135
4.8.5.12	Function of Muscles in Protecting the Cervical Spine	138
4.8.5.13	Flexibility	138
4.8.5.14	Neural Tissue Mobilising Exercises	141
4.8.5.15	Balance	141
4.9	SUMMARY	144

CHAPTER 5: LITERATURE REVIEW ON CERVICAL

SPINE INJURIES IN RUGBY-----145

5.1	INTRODUCTION	145
5.2	INCIDENCE OF CERVICAL SPINAL CORD INJURIES	146
5.3	PREDISPOSING FACTORS FOR CERVICAL SPINAL CORD INJURY	148
5.4	MECHANISM OF INJURY	148
5.4.1	Failure Models of Ligament versus Bone	149
5.4.2	Physiologic Strains of Ligaments	149
5.4.3	A Kinematic Approach to Mechanism of Injury	150
5.5	PREVENTION OF CERVICAL SPINE INJURIES	157
5.6	SUMMARY	158

CHAPTER 6: EMPIRICAL STUDY-----159

6.1	THE IMPORTANCE OF EVIDENCE BASED PRACTICE	159
6.2	PILOT STUDY	160
6.2.1	Aim	160
6.2.2	Method	161
6.2.3	Results	161
6.2.4	Conclusion for the thesis study	163

6.3	STUDY DESIGN	164
6.3.1	Blinding	164
6.4	STUDY POPULATION	165
6.5	STUDY SAMPLE	165
6.5.1	Inclusion Criteria	166
6.5.1.1	Inclusion Criterion for all Participating Subjects	166
6.5.1.2	Specific Inclusion Criterion for Groups 1 and 2	166
6.5.1.3	Specific Inclusion Criterion for Group 3	167
6.5.2	Exclusion criteria	167
6.6	ETHICAL CONSIDERATIONS	168
6.7	MEASUREMENT TOOLS AND INSTRUMENTS	168
6.8	PROCEDURES	169
6.8.1	Initial sifting	169
6.8.2	Validation of the Manual Physiotherapy Evaluation Technique for Motion Segment Analysis	170
6.8.3	Detailed Physiotherapy Assessment	173
6.8.3.1	Subjective Evaluation	173
6.8.3.2	Age and Anthropometric Measurements	174
6.8.3.3	Ligament Stability Upper Cervical Spine	174
6.8.3.4	Motion segment analysis	175
6.8.3.5.	Neurodynamic Testing	175
6.8.3.6	Posture	176
6.8.4	Radiography	178
6.8.4.1	Technique for X-ray Examination	178
6.8.4.2	Measurements Performed	178
6.8.4.3	Analysis of Digitised X-ray Films	180
6.8.5	Manual Physiotherapy Treatment Technique	180
6.8.6	Therapeutic Exercise Programme for Correction of Biomechanical Dysfunction	182
6.8.7	Neck Rehabilitation Programme	184

6.8.7.1	General Principles when Performing the Rehabilitation Programme	185
6.8.7.2	Strengthening and Re-establishing Neuromuscular Control	187
6.8.7.3	Cervical Spine Mobilising Exercises	192
6.8.7.4	Neck Stability Exercises	194
6.8.7.5	Flexibility Exercises	200
6.8.7.6	Nerve mobilising exercises	203
6.8.7.7	Balance	207
6.8.7.8	Player Education for the Neck Rehabilitation Programme	209
6.9	STATISTICAL ANALYSIS	210
6.10	SUMMARY	210

CHAPTER 7: RESULTS AND DISCUSSION OF THE EMPIRICAL STUDY		211
7.1	INTRODUCTION	211
7.2	INTERPRETING BIOMECHANICAL DYSFUNCTION IN TERMS OF X-RAY MEASUREMENTS	212
7.3	GROUP 1. TESTING THE MANUAL PHYSIOTHERAPY TECHNIQUE FOR CORRECTION OF BIOMECHANICAL DYSFUNCTION.	215
7.3.1	Results of the Flexion angle X-ray measurements for Group 1	215
7.3.2	Results of the Extension angle X-ray measurements for Group 1	217
7.3.3	Results for Angles of rotation of Group 1	218
7.3.4	Results for the Translation X-ray measurements for Group 1	220
7.3.5	Effect sizes (d-values) for the various x-ray measurements for Group 1 Before and After Manual Physiotherapy Treatment	222
7.4	GROUPS 2 AND 3. THERAPEUTIC EXERCISE PROGRAMME FOR THE CORRECTION OF BIOMECHANICAL DYSFUNCTION	224

7.4.1	Testing the Effectiveness of the Therapeutic Exercise	
	Programme performed by Group 2	225
7.4.1.1	Results for Flexion angles measured for Group 2	225
7.4.1.2	Results for Extension X-ray measurements for Group 2	226
7.4.1.3	Results for Angles of Rotation X-ray measurements for Group 2	228
7.4.1.4	Results of the Translation X-ray measurements for Group 2	229
7.4.1.5	Effect sizes (d-values) for the various x-ray measurements for Group 2 Following the Completion of the Therapeutic Exercise Programme	231
7.4.2	Group 3. Testing the Safety of the Therapeutic Exercise Programme	233
7.4.2.1	Results of the flexion x-ray measurements for Group 3	233
7.4.2.2	Results of the Extension X-ray measurements for Group 3	234
7.4.2.3	Results for the Angles of Rotation X-ray measurements for Group 3	236
7.4.2.4	Results for the translation x-ray measurements for Group 3	237
7.4.2.5	Effect sizes (d-values) for the various Motion Segment X-ray measurements performed for Group 3 before and after the Therapeutic Exercise Programme	239
7.5	GROUP 4. RESULTS FOR THE CONTROL GROUP	240
7.5.1	Results of the Flexion angle X-ray Measurements for Group 4	240
7.5.2	Results of the mean Extension angles for Group 4, the control group	242
7.5.3	Results of the Angles of Rotation for Group 4	243
7.5.4	Results of the Translation Measurements for Group 4	245
7.5.5	Effect sizes (d-values) for all the Motion Segment X-ray Measurements of Group 4	246
7.6	TESTING THE NECK REHABILITATION PROGRAMME	247

7.6.1	Results of Cervical Circumference following the Neck Rehabilitation Programme	248
7.6.2	Results of X-ray Measurements following the Neck Rehabilitation Programme	252
7.6.2.1	Flexion angle Results following the Rehabilitation Programme	252
7.6.2.2	Extension angle results following the Rehabilitation programme	255
7.6.2.3	Results for the Angles of Rotation following the Rehabilitation programme	259
7.6.2.4	Results for the Translation Measurements following the Neck Rehabilitation Programme	262
7.6.2.5	Explanation for the Improvement in Biomechanical Function following the Rehabilitation Programme	267
7.6.3	Role of the Educator in the Neck Rehabilitation Programme	268
7.7	FACTORS WHICH COULD PREDISPOSE A SCHOOLBOY RUGBY PLAYER TO CERVICAL SPINE BIOMECHANICAL DYSFUNCTION	270
7.7.1	Results for Posture possibly Influencing Biomechanical Function	270
7.7.2	Age and Anthropometric Measurements results	275
7.7.3	Upper cervical spine Ligament stability results	276
7.7.4	Results of the Neurodynamic testing	276
7.7.5	Results for Playing Position	277
7.8	PREVENTION OF CERVICAL SPINAL CORD INJURIES	278
7.9	PREVENTION OF EARLY CERVICAL SPINE DEGENERATION	280
7.9.1	The Biomechanical Consequence of Degeneration	288
7.10	SUMMARY	289

CHAPTER 8: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	291
8.1 SUMMARY	291
8.2 CONCLUSIONS	297
8.2.1 Primary Physiotherapeutic Aim: Motion segment analysis using the physiotherapeutic evaluation technique	297
8.2.2 Primary Physiotherapeutic Aim: Manual physiotherapy Technique in the correction of Biomechanical Dysfunction	299
8.2.3 Primary Education Aim: Therapeutic Exercise Programme for the correction of Biomechanical Dysfunction	299
8.2.4 Primary Education Aim. The Neck Rehabilitation Programme	301
8.2.5 Secondary Aim: Posture and Biomechanical Dysfunction	303
8.2.6 Secondary Aim: Playing position and Biomechanical Dysfunction	303
8.3 RECOMMENDATIONS	304
8.3.1 Manual Physiotherapy Evaluation and Treatment Technique	304
8.3.2 Therapeutic Exercise Programme for the correction of Biomechanical Dysfunction and Neck Rehabilitation Programme	306
8.3.3 Normative values for motion segment analysis for schoolboy rugby players	307
8.3.4 Recommendations for future studies	308
8.4 LIMITATIONS	309
REFERENCES	310
APPENDICES	339

LIST OF TABLES

Table 4.1:	Normative values for mean angles of rotation-----	79
Table 7.1:	Normative values for mean angles of rotation-----	213
Table 7.2:	Results of the flexion angles for Group 1 before and after manual physiotherapy treatment.-----	216
Table 7.3:	Results of the extension angles for Group 1 following the manual physiotherapy treatment.-----	217
Table 7.4:	Results for the angles of rotation, Group 1, before and after manual physiotherapy treatment.-----	219
Table 7.5:	Results for translation before and after manual physiotherapy treatment for the players of Group 1.-----	220
Table 7.6:	Results of the flexion angles for Group 2, before and after the therapeutic exercise programme.-----	225
Table 7.7:	Results for extension angles for Group 2 before and after completing the therapeutic exercise programme.-----	227
Table 7.8:	Results for the angles of rotation x-ray measurements for Group 2 before and after completing the therapeutic exercise programme.-----	228
Table 7.9:	Results of the translation x-ray measurements for Group 2 before and after completing the therapeutic exercise programme.-----	230
Table 7.10:	Results of the flexion x-ray measurements for Group 3 before and after the therapeutic exercise programme.-----	233

Table 7.11:	The results of the mean extension angles for Group 3 before and after completing the therapeutic exercise programme.-----	235
Table 7.12:	The results of the mean angles of rotation for Group 3 before and after completing the therapeutic exercise programme.-----	236
Table 7.13:	Results for the mean translation x-ray measurements for the Group 3 before and after the therapeutic exercise programme.-----	238
Table 7.14:	The results of the mean flexion angles for the first and second sets of x-rays for Group 4.-----	241
Table 7.15:	Results of the extension angles measured on x-rays for Group 4.-----	242
Table 7.16:	Results of the angles of rotation for the first and second sets of x-rays for Group 4.-----	244
Table 7.17:	Results of the translation measurements for Group 4.-----	245
Table 7.18:	Cervical circumference results of the various compliance groups for all the players who completed the rehabilitation programme.-----	249
Table 7.19:	Body mass results of the various compliance groups for all the players who completed the rehabilitation programme.-----	250
Table 7.20:	Results of the flexion angles for the C6/C7 motion segment before and after the neck rehabilitation programme.-----	252
Table 7.21:	Results of the flexion angles for the C5/C6 motion segment before and after the neck rehabilitation programme.-----	253

Table 7.22:	Results of the flexion angles for the C4/C5 motion segment before and after the neck rehabilitation programme.-----	253
Table 7.23:	Results of the flexion angles for the C3/C4 motion segment before and after the neck rehabilitation programme.-----	254
Table 7.24:	Results of the total flexion angles for all the motion segment measured before and after the neck rehabilitation programme.-----	254
Table 7.25:	Results of the extension angles for the C6/C7 motion segment before and after the neck rehabilitation programme.-----	256
Table 7.26:	Results of the extension angles for the C5/C6 motion segment before and after the neck rehabilitation programme.-----	256
Table 7.27:	Results of the extension angles for the C4/C5 motion segment before and after the neck rehabilitation programme.-----	257
Table 7.28:	Results of the extension angles for the C4/C5 motion segment before and after the neck rehabilitation programme.-----	257
Table 7.29:	Results of the total extension angles for all the motion segments measured before and after the neck rehabilitation programme.-	258
Table 7.30:	Results for the angles of rotation for the C6/C7 motion segment before and after the neck rehabilitation programme.-----	260
Table 7.31:	Results for the angles of rotation for the C5/C6 motion segment before and after the neck rehabilitation programme.-----	260
Table 7.32:	Results for the angles of rotation for the C4/C5 motion segment before and after the neck rehabilitation programme.-----	261

Table 7.33:	Results for the angles of rotation for the C3/C4 motion segment before and after the neck rehabilitation programme.-----	261
Table 7.34:	Mean translation measurement results for C6/C7 motion segment before and after the neck rehabilitation programme.-----	263
Table 7.35:	Mean translation measurement results for C5/C6 motion segment before and after the neck rehabilitation programme.-----	263
Table 7.36:	Mean translation measurement results for C4/C5 motion segment before and after the neck rehabilitation programme.-----	264
Table 7.37:	Mean translation measurement results for C3/C4 motion segment before and after the neck rehabilitation programme.-----	264
Table 7.38:	Mean flexion angles for the various posture types for Group 1, C6/C7 motion segment.-----	272
Table 7.39:	Mean flexion angles for the various posture types for Group 2, C4/C5 motion segment.-----	272
Table 7.40:	Mean flexion angles for the various posture types for Group 2, C5/C6 motion segment.-----	273
Table 7.41:	Mean flexion angles for the various posture types for Group 2, C6/C7 motion segment.-----	273
Table 7.42:	Mean flexion angles for the various posture types for Group 3, C3/C4 motion segment.-----	273
Table 7.43:	Mean flexion angles for the various posture types for Group 3, C4/C5 motion segment.-----	273

Table 7.44:	Mean flexion angles for the various posture types for Group 3, C5/C6 motion segment.-----	274
Table 7.45:	Mean flexion angles for the various posture types for Group 4, C4/C5 motion segment.-----	274
Table 7.46:	Mean flexion angles for the various posture types for Group 4, C6/C7 motion segment.-----	274
Table 7.47:	Mean anthropometric measurements for the various groups.—	276

LIST OF FIGURES

Figure 1.1:	The prevalence of cervical dysfunction according to forward and back playing positions in the total sample.	6
Figure 3.1:	Skeletal muscle components.	30
Figure 3.2:	Muscle fibre components.	30
Figure 3.3:	Bulging of the annulus fibrosus on the concave side of the bending curve.	52
Figure 3.4:	A typical load-deformation curve of a spinal ligament, obtained in a material testing machine.	61
Figure 4.1:	Unit vector. Orientation of the facet plane of the lower cervical vertebra is advantageously defined with the help of the concept of the unit vector.	68
Figure 4.2:	Right-handed Cartesian: x, y, z. Translations (Tx, Ty, Tz) along the direction of the arrows and clockwise rotations (Rx, Ry, Rz) around the arrows are considered as positive motions. The opposite motions are negative.	70
Figure 4.3:	Orientation of the cervical facet joints represented graphically at approximately 45° to the x-axis.	73
Figure 4.4:	Method for measuring extension angle for a motion segment in the cervical spine region.	80
Figure 6.1:	Flowchart to illustrate the selection sample population.	160
Figure 6.2:	Results of the pilot study for Group A.	162

Figure 6.3:	Results of the pilot study for Group B.	163
Figure 6.4:	The effect sizes (d-values) for the results testing the validity of the Physiotherapy Evaluation Technique.	172
Figure 6.5:	Upper limb neurodynamic test (ULTT1).	176
Figure 6.6:	Ideal (A), Kyphosis-lordosis (B), Flat back (C) and sway back postures.	176
Figure 6.7:	Forward head posture.	177
Figure 6.8:	Examples of scoliosis curve patterns.	177
Figure 6.9:	Method for measuring extension angle for a motion segment in the cervical spine region.	179
Figure 6.10:	Illustration of the first movement pattern included in the therapeutic exercise programme performed by the players of Groups 2 and 3.	183
Figure 6.11:	Illustration of the second movement pattern included in the therapeutic exercise programme performed by the players of Groups 2 and 3.	183
Figure 6.12:	Core stability exercise using transversus abdominis.	186
Figure 6.13:	Watch exercise for shoulder girdle stability.	187
Figure 6.14:	Phase one deep cervical flexor strengthening exercise.	188
Figure 6.15:	Progression of phase one deep cervical flexor strengthening exercise.	188

Figure 6.16	Phase two deep neck flexor exercise with Theraband resistance.	189
Figure 6.17:	Proprioceptive neuromuscular facilitation movement pattern without resistance for phase one of the rehabilitation programme.	190
Figure 6.18:	Proprioceptive neuromuscular facilitation movement pattern with resistance for phase two of the rehabilitation programme.	191
Figure 6.19:	Proprioceptive neuromuscular facilitation movement pattern with resistance for phase three of the rehabilitation programme.	191
Figure 6.20:	Mobilising exercise for cervical rotation for phase one of the neck rehabilitation programme.	192
Figure 6.21:	Mobilising exercise for extension of the spine for phase two of the neck rehabilitation programme.	193
Figure 6.22:	Mobilising exercise for flexion of the spine for phase two of the neck rehabilitation programme.	193
Figure 6.23:	Phase one neck stability exercise included in the neck rehabilitation programme.	194
Figure 6.24:	Phase two and three neck stability exercise included in the neck rehabilitation programme.	195
Figure 6.25:	Shoulder stand sequence for neck stability included for phase two and three of the neck rehabilitation programme.	196
Figure 6.26:	Sequence for the head stand included in phase two and three of the neck rehabilitation programme.	198

Figure 6.27: Shoulder stand position used for the perturbation exercise included in phase three of the neck rehabilitation programme.	199
Figure 6.28: Position assumed for the closed kinetic dynamic stability exercise included in phase three of the neck rehabilitation programme.	200
Figure 6.29: Starting position of all the stretches for all three phases of neck rehabilitation.	201
Figure 6.30: Stretch for the lateral neck muscles included for phases one, two and three of the rehabilitation programme.	202
Figure 6.31: Stretch for the posterior neck muscles as performed during phases one, two and three of the rehabilitation programme.	202
Figure 6.32: Stretch for the prevertebral and lateral neck muscles as performed during phases one, two and three of the rehabilitation programme.	203
Figure 6.33: Nerve mobilising exercise for phase one of the rehabilitation programme.	204
Figure 6.34: Phase two nerve mobilising exercise included in the rehabilitation programme.	205
Figure 6.35: First nerve mobilising exercise included in phase three of the rehabilitation programme.	206
Figure 6.36: Second nerve mobilising exercise included in phase three of the rehabilitation programme.	206

Figure 6.37: Phase one balance exercise included in the rehabilitation programme.	207
Figure 6.38: Phase two balance exercise included in the rehabilitation programme.	208
Figure 6.39: Phase three balance exercise included in the rehabilitation programme.	209
Figure 7.1: Results of the flexion angles for Group 1 before and after manual physiotherapy treatment.	216
Figure 7.2: Results of the extension angles for Group 1 following the manual physiotherapy treatment.	218
Figure 7.3: Results for the angles of rotation, Group 1, before and after manual physiotherapy treatment.	219
Figure 7.4: Results for translation before and after manual physiotherapy treatment for the players of Group 1.	221
Figure 7.5: Effect sizes (d-values) for the various x-ray measurements performed on the motion segments of the cervical spine before and after manual physiotherapy treatment of Group 1.	223
Figure 7.6: Results of the flexion angles for Group 2, before and after the therapeutic exercise programme.	226
Figure 7.7: Results for extension angles for Group 2 before and after completing the therapeutic exercise programme.	227
Figure 7.8: Results for the angles of rotation x-ray measurements for Group 2 before and after completing the therapeutic exercise programme.	229

Figure 7.9:	Results of the translation x-ray measurements for Group 2 before and after completing the therapeutic exercise programme.-----	230
Figure 7.10:	Effect sizes (d-values) for the various x-ray measurements performed before and after the therapeutic exercise programme for Group 2.-----	232
Figure 7.11:	Results of the flexion x-ray measurements for Group 3 before and after the therapeutic exercise programme.-----	234
Figure 7.12:	The results of the mean extension angles for Group 3 before and after completing the therapeutic exercise programme.-----	235
Figure 7.13:	The results of the mean angles of rotation for Group 3 before and after completing the therapeutic exercise programme.-----	237
Figure 7.14:	Results for the mean translation x-ray measurements for the Group 3 before and after the therapeutic exercise programme.-	238
Figure 7.15:	Effect sizes (d-values) for all the x-ray measurements for Group 3.-----	239
Figure 7.16:	The results of the mean flexion angles for the first and second sets of x-rays for Group 4.-----	241
Figure 7.17:	Results of the extension angles measured on x-rays for Group 4.-----	243
Figure 7.18:	Results of the angles of rotation for the first and second sets of x-rays for Group 4.-----	244
Figure 7.19:	Results of the translation measurements for Group 4.-----	245

Figure 7.20:	Results of the effect sizes (d-values) for Group 4.	-----246
Figure 7.21:	Effect sizes (d-values) of the various compliance groups for all the players who completed the neck rehabilitation programme.	-----249
Figure 7.22:	Normative flexion angle measurements for cervical spine motion segments C3 to C7 as well as total flexion.	-----255
Figure 7.23:	Normative extension angle measurements for cervical spine motion segments C3 to C7 as well as total extension.	-----259
Figure 7.24:	Normative angles of rotation measurements for cervical spine motion segments C3 to C7.	-----262
Figure 7.25:	Normative translation measurements for cervical spine motion segments C3 to C7.	-----265
Figure 7.26:	Normative values for all the x-ray measurements performed following the neck rehabilitation programme for cervical spine motion segments C3 to C7.	-----266
Figure 7.27:	Eta squared values illustrating the correlation between posture and biomechanical dysfunction for the various Groups.	-----271
Figure 7.28:	Comparison between forwards and backs.	-----277
Figure 7.29:	A schematic illustration of the normal biomechanics of the cervical spine with the functional force being transmitted through the posterior third of the vertebral body.	-----281
Figure 7.30:	Flexion x-ray measurement for the motion segments of one of the players from Group 1, prior to the manual physiotherapy treatment.	-----283

Figure 7.31:	A schematic illustration of the effect that excessive flexion could have on the posterior fibres of the annulus fibrosus of the intervertebral disc.	-----284
Figure 7.32:	Flexion x-ray measurement for the motion segments of one of the players from Group 1, after the manual physiotherapy treatment.	-----285
Figure 7.33:	Flexion x-ray measurement for the motion segments of one of the players from Group 1, following the neck rehabilitation programme.	-----286
Figure 8.1:	Normative values for all the x-ray measurements performed following the neck rehabilitation programme for cervical spine motion segments C3 to C7.	-----309

Chapter 1

Perspectives and Problem statement

1.1 Introduction

Prevention of injury, disease and ill-health, the promotion of health and the reduction in the cost of medical treatment, have become the most significant public health trends over the last two decades. Health systems around the world, including South Africa, are being overloaded whilst the physiotherapy profession is in a perfect cost effective position to contribute to the prevention of many neuromusculoskeletal disorders. Education plays a significant role in this prevention process. Educating and informing young adults about their musculoskeletal health and providing them with programmes which could help with the prevention of orthopaedic conditions could form the keystone for managing neuromusculoskeletal disorders in the future. This investigation will target the schoolboy rugby player in the development of an effective programme which could ultimately contribute to the prevention of serious cervical spinal cord injury as well as in the prevention of early degenerative changes found in the cervical spines of adult rugby players.

Tofler (1980) describes three waves of human societal evolution, the first wave from hunter-gatherer to agricultural society, the second from agricultural to industrial based society, and the third wave from industrial to information based society. Personal computers have been the main tool in the development of this information based society. The complication developing from this information based society is that the individual now has a sedentary lifestyle which does not support a healthy spine. Add to this trend a sport like rugby, where the neck of the rugby player is at risk of injury or developing a musculoskeletal disorder, and the importance of an early prevention programme could therefore be considered as crucial. The World Health Organisation (WHO) suggests a biopsychosocial model in the management of any musculoskeletal condition and therefore a prevention programme for the intervention of orthopaedic conditions should also be based on this biopsychosocial model.

1.2 Rugby

Rugby is a full contact sport with intermittent high intensity activity, which combines a unique blend of aerobic, anaerobic and strength requirements. Consequently the risk of injury has always been high and is becoming more of an issue due to the increased competitiveness of the game. In recent years rugby playing nations of the world, including the United Kingdom (Silver, 1984), Australia (Taylor & Coolican, 1988) and South Africa (Kew *et al*, 1991; Scher, 1980, 1981, 1982), showed increased concern about the long-term effects of rugby injuries on the neuromusculoskeletal system, as well as on the emotional state of the player is of equal importance to the bio-psychosocial profile of an injured player. The direct and indirect cost involved following a sustained injury.

The inherent risks in the game of rugby encouraged an increasing number of parents to refuse permission for their children to participate in the game. During the 2001 South African schools rugby season no less than six schoolboys sustained fatal head and spinal injuries (Jakoet, 2002). The need to investigate ways of reducing or preventing injuries are therefore of paramount importance to ensure that rugby continues to grow as a popular spectator sport in South Africa. The trauma resulting from rugby injuries could possibly be reduced by investigating predisposing factors for injuries and correcting these where possible.

Predisposing factors for rugby injuries could broadly be divided into intrinsic and extrinsic factors. Intrinsic factors are individual biological and psychosocial characteristics predisposing a player to sustain a neuromusculoskeletal injury (Taimela *et al*, 1990). Extrinsic factors are independent of the injured player and are in the main related to the type of activity taking place resulting in an injury (Taimela *et al*, 1990). External mechanisms could act on the body, for example a player being tackled by an opponent. Some examples of how extrinsic factors have been addressed to reduce injuries are the following:

- the rule changes implemented by the International Rugby Board to prohibit high tackles and collapsing of the scrum;

- the scrum should not turn more than 90°;
- implementation of the “crouch–touch–pause–engage” scrum technique (Noakes & Du Plessis, 1996:40).

To date very few studies have been conducted where the emphasis was placed on the correction of intrinsic factors. The proposed study will evaluate the biomechanics of the cervical spine and the effects of a manual physiotherapeutic technique aiming to correct any dysfunction. This could form the start of a long term follow-up study to investigate whether the implementation of this technique in schoolboy rugby players may reduce the number of cervical injuries and prevent early degenerative changes found in the cervical spines of rugby players.

Intrinsic injuries may occur due to a structural or functional biomechanical abnormality within the body, which, if left untreated could result in overuse injuries. Overuse injuries occur when the body is unable to adapt to the cumulative stress of a repetitively applied force. This compromises the ability of tissue to repair itself (Giffen & Stanish, 1993).

Many of the injuries occurring during a rugby match or practice session involve the muscles, tendons, ligaments and joints and could possibly lead to early degeneration of these structures (Lee *et al*, 2001). These degenerative changes could take up to 20 years before clinical symptoms are developed. Repetitive and rapidly applied impulsive loading has been shown to produce joint degeneration, whereas slowly applied loads of equal or even greater magnitude often have no deleterious effects (Radin, 1986). This places the rugby player at risk of developing joint degeneration within the cervical spine region, since during certain phases of play such as the tackle and the scrum, the player may be subjected to rapidly applied forces.

1.3 Physiotherapy in Biomechanics

Central to understanding the development of orthopaedic conditions through a process of wear and tear lays biomechanics. Biomechanics is one of the disciplines in the field of human movement science described by Nigg (1985) and Lees (1999) as the science

that applies mechanical principles to understand the functioning of the neuromusculoskeletal system. Biomechanics covers a very wide field and there are many disciplines that form part of biomechanical assessment.

The role of the sport physiotherapist in the field of biomechanics is to assess the athlete according to biomechanical principles, using physiotherapeutic assessment techniques and then to correct as far as professionally possible, any identified structural and / or functional abnormalities. The skilled physiotherapist should then apply this knowledge, using orthopaedic manual physiotherapy techniques, to prevent or reduce the incidence of injury. However in the event of an injury occurring, the same principles should be applied in the rehabilitation of the athlete. The age of athletes participating in competitive sport has decreased, and therefore the physiotherapist may see a large number of young athletes who develop biomechanical abnormalities whilst still in the growing phase. It is very important to manage these young athletes effectively and try to prevent the development of any long-term negative effects, because of inadequate or ineffective rehabilitation (Kemper, 2000).

The schoolboy rugby player is such an athlete who is growing and developing physically, and therefore the role players involved with schoolboy rugby players should share in the responsibility to inform and educate the schoolboy rugby player in the prevention of injury or dysfunction. These role players should equip the schoolboy rugby player with a set of tools which he can apply to be in control of his own cervical spine. The schoolboy rugby player should use the knowledge provided by his rugby support system to improve his future life.

1.4 Motion Segment Analysis

In order to function optimally joints should be in a physiological state of rest with the least amount of intra-articular pressure, least amount of connective tissue tension and the least amount of electromyographic (EMG) muscle activity. When a motion segment cannot move normally in the three planes of space, a biomechanical dysfunction occurs. When a motion segment is held in a position of dysfunction, the movement of that specific segment will be restricted, and therefore the motion

segment is unable to move as required by the body. For example, when one considers a motion segment of the cervical spine which is held in a dysfunctional position this could result in altered flexion / extension motion and / or loss of the normal cervical lordosis. If the cervical spine is then forced into hyper-flexion, for example during a tackle or when the scrum collapses, the dysfunctional motion segment could be forced beyond normal range of motion since normal motion patterns are altered and therefore the probability of injury is increased.

For a physiotherapist to determine the presence of biomechanical dysfunction in the cervical spine it is necessary to analyse each motion segment of the cervical spine using a reliable, cost effective physiotherapy evaluation technique. No validated physiotherapy evaluation technique for motion segment analysis was found in the literature reviewed. However, many biomechanical models for the movement of the cervical spine were found in the literature reviewed (Onan *et al*, 1998; Mercer & Bogduk; 2001; Bogduk & Mercer, 2000; Panjabi, 1998; Patwardhan *et al*; 1982, Kaigle *et al*, 1997; Moroney *et al*, 1988; Goel & Clausen, 1998; Wu & Chen, 1996; Shirazi-adl *et al*, 1986 and Simon *et al*, 1985). None of these models suggested a technique which could be used by a physiotherapist to determine biomechanical dysfunction of the cervical spine. The researcher attended a course presented by Rocabado (1999) who suggested a movement pattern of the cervical spine that would suggest certain restrictions and concluded that this could be used to predict the motion of the cervical spine. The question asked is therefore whether this proposed evaluation will be valid and reliable in determining cervical biomechanical dysfunction.

1.5 Biomechanical Dysfunction found in Schoolboy Rugby Players

Biomechanics of the cervical spine was evaluated as part of the assessment of 67 schoolboy rugby players in a previous research project, using the manual therapy evaluation techniques which will be studied for this investigation (Steyn, 2002). A player was said to have cervical biomechanical dysfunction if one or more positional faults were found in the intervertebral motion segments of his cervical spine.

Cervical biomechanical function of forward and backline players was compared. In this project it was hypothesised that the forward players would have a higher incidence of cervical dysfunction compared to the backs, due to the impact and forces acting on the neck in the scrum. However, the results, using Pearson Chi-square, did not indicate a statistically significant difference between the two groups ($p = 0,255$). See Figure 1.1 for the prevalence of cervical dysfunction according to forward and back playing positions in the sample.

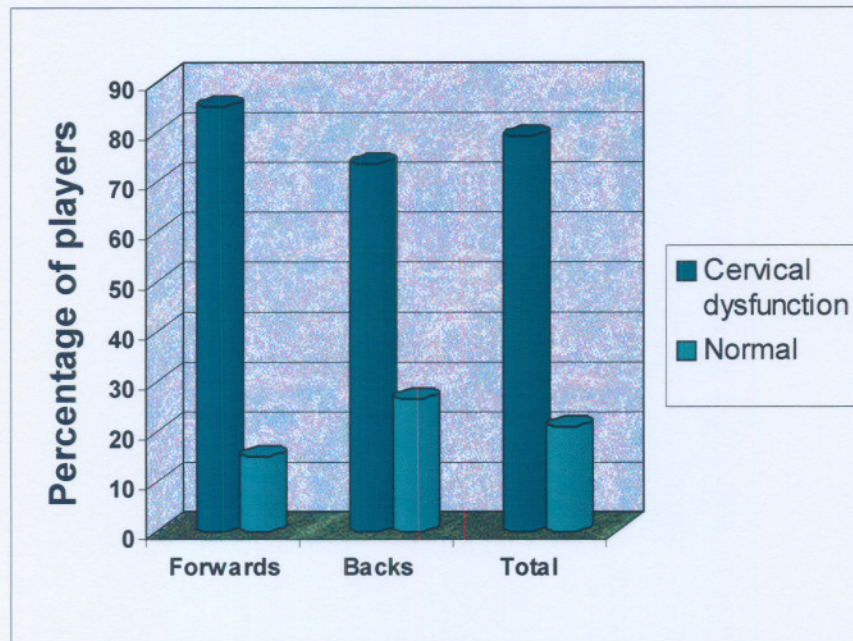


Figure 1.1: The prevalence of cervical dysfunction according to forward and back playing positions in the total sample (Steyn, 2002).

A possible explanation for the high incidence of cervical dysfunction in back-line players (74 %) (Steyn, 2002) could be due to incorrect tackling techniques, such as spearing, which may cause cervical biomechanical dysfunction. The high contribution of the tackle to injury episodes could reflect recent rule changes that encourage open play conducted at high speeds to enhance the game as a flowing spectator sport. The challenge now is to sustain the popularity of the game, while reducing potential trauma following high-velocity contact of the tackle (Garraway & Macleod, 1995).

Results (Steyn, 2002) from the project showed that of the total sample, 49 subjects presented with biomechanical dysfunction at the C6/C7 motion segment, 40 subjects had dysfunction at the C5/C6 motion segment and 26 subjects at the C4/C5 motion segment. The stability of the transverse and alar ligaments was evaluated and these results indicated that all the subjects' tested ligaments were stable.

1.6 Manual Physiotherapy for the Correction of Biomechanical Dysfunction

Once biomechanical dysfunction is determined in an individual the challenge for the physiotherapist is to effectively correct this dysfunction. In the literature reviewed no physiotherapy treatment technique for correcting the biomechanical dysfunction suspected to be present in the schoolboy rugby players could be found. This study will therefore investigate the effectiveness of a manual physiotherapy treatment technique for the correction of the biomechanical dysfunction.

In the recent economical climate of South Africa with the development of rugby to the previously disadvantaged communities a cost effective method, of correcting cervical biomechanical dysfunction for the communities that do not have access to physiotherapy treatment, should be provided. This research study will test the effectiveness of a therapeutic exercise programme, for the correction of biomechanical dysfunction, based on a manual physiotherapy treatment technique. This programme should then be implemented for all schoolboy rugby players to restore normal biomechanics of the cervical spine. The safety of such a programme will also be investigated to support the implementation of this programme for all schoolboy rugby players with no adverse affects.

1.7 Early Degeneration

According to Steyn (2002) the 79 % incidence of cervical dysfunction of the total sample is of major clinical importance. This dysfunction of the motion segments could result in various pathologies (Dai *et al*, 1992):

- The constant stress on the soft tissues of a motion segment in the cervical spine could possibly result in early degenerative changes of the cervical spine;
- In more serious cases this excessive flexion could contribute to the dislocation of the facet joints, resulting in spinal cord injury;
- The posterior wall of the outer fibres of the disc is stretched with cervical flexion and this may cause the outer rings of the annulus fibrosis of the disc to be torn potentially resulting in a disc herniation.

It could be theorised that the biomechanical dysfunction found in the cervical spines of the schoolboy rugby players evaluated could be the reason why rugby players show signs of early degenerative changes of their cervical spines on X-ray. Scher (1990) suggested that rugby players are prone to early degenerative changes of the cervical spine. He performed lateral radiographs of the cervical spines of 150 rugby players, still actively involved club rugby. Three groups of 50 players aged between 20 to 25 years, 25 to 30 years and 30 to 35 years were selected. Each group included 25 forwards and 25 backs. All the subjects included were volunteers and participated in the investigation with the co-operation of the secretaries of senior rugby clubs in Cape Town, South Africa. All the subjects were asymptomatic at the time of the investigation. A control group of 150 men who did not play rugby was selected from patients referred to the Department of Radiology from the General Outpatients Department of the Tygerberg hospital, Cape Town. Similar criteria for selection were followed in order to provide a matched sample with regard to age. These volunteer subjects had no symptoms or signs of arm or neck pain at the time of the examination. The study revealed that rugby players showed premature and advanced degenerative changes of degenerative disease when compared to the control group. These changes were most marked in the cervical spines of the tight forwards.

O'Brien (1996) described case studies of two adult front row players who were found to have chronic vertebral and disc degeneration on x-rays. He concluded that the high loading of the cervical spine endured by these two front row players was the cause of the vertebral and disc degeneration. He suggested that when assessing the cervical spine of a front row player the clinician should be conscious of the possibility of degenerative changes, even in the event of a minor injury.

1.8 Cervical Spine Injuries

There are many different structures within the body that are prone to overload injury and each of these structures has a different critical limit or point of structural failure. For the schoolboy rugby player structural failure of the cervical spine could result in detrimental spinal cord injury with catastrophic results. Load analysis of these critical limits becomes extremely complicated. Thus, the objective is to find ways of reducing the load on the structures, thereby reducing the risk of exceeding the critical limits (Lees, 1999). Correcting possible cervical biomechanical dysfunction of the intervertebral motion segments may reduce the load on these cervical spine structures. It is therefore important to correct any possible cervical biomechanical dysfunction in schoolboy rugby players.

Various authors suggested that cervical spinal cord injuries could be reduced or prevented by strengthening the necks of rugby players (Scher, 1998; Noakes & Jakoet; 1995 and Silver, 1988). The dominant mechanism for sustaining muscle strength is seen in an increase in the size of the muscle (Bloomfield *et al*, 1994:123). According to Scher (1990) the circumference of the neck should be measured to indicate an improvement in muscle power of the cervical neck musculature. There are presently more sophisticated measurement instruments to measure neck muscle strength such as the isokinetic cybex measurement instrument. The objective of this study was to provide the schoolboy rugby player and his coach with a programme that does not require costly high tech equipment in the measurement and execution of the programme.

Care should however be taken when prescribing a strengthening programme for the necks of schoolboy rugby players. A player may have cervical motion segments in a position of dysfunction for many years without experiencing any pain. It could be hypothesised that if the motion segments of the cervical spine of a player are held in a dysfunctional position and cannot move normally in the three planes of space, certain exercises could strain the motion segments of the cervical spine, exacerbating the dysfunction. Strengthening exercises could also stabilise the cervical spine in a

position of dysfunctional, exacerbating any predisposition to injury or early degeneration. Before prescribing a neck rehabilitation programme for schoolboy rugby players any cervical spine biomechanical dysfunction should first be corrected and then maintained while establishing normal movement patterns.

The programme developed for the purpose of this study could not be considered as a pure strengthening programme with hypertrophy of the neck muscles as the only aim. This is a rehabilitation programme to restore normal movement patterns of the neck as well as teaching the schoolboy rugby player neuromuscular control of the cervical spine. Principles of motor learning were used in the development of this rehabilitation programme.

As mentioned earlier education could form the keystone in the prevention of many musculoskeletal disorders by educating and implementing various prevention programmes for young people. Various role players such as the physiotherapist, coach or educators concerned with the safety of the cervical spine of schoolboy rugby players, could implement the therapeutic exercise programme for the correction of biomechanical dysfunction as well as the neck rehabilitation programme. This programme will also provide the schoolboy rugby player with an opportunity to become knowledgeable concerning the safety as well as an opportunity of taking control and responsibility for the wellbeing of his own neck.

Since the literature reviewed yielded no research investigating the physiotherapeutic or therapeutic exercise management of cervical biomechanical dysfunction, it was decided to evaluate the efficacy of manual physiotherapy techniques in the management of cervical biomechanical dysfunction in schoolboy rugby players. Management includes both the diagnosis and treatment of cervical spine biomechanical dysfunction as well as rehabilitation in order to maintain in a healthy cervical spine. The following research question could therefore be asked:

1.9 Research Question

Could a manual physiotherapy approach be used to determine and correct cervical biomechanical dysfunction in schoolboy rugby players, as well as rehabilitating the neck to maintain the correction?

1.10 Aims and objectives

1.10.1 Primary Physiotherapeutic Aims

- To test the effectiveness of a manual physiotherapy treatment technique, performed by a skilled physiotherapist, in the correction of cervical biomechanical dysfunction.
- To validate a manual physiotherapy evaluation technique in motion segment analysis of the cervical spine by objectively comparing results with x-ray measurements.

1.10.2 Primary Education Aims

- To study the effectiveness and safety of a therapeutic exercise programme, based on a manual physiotherapy technique, for the correction of cervical biomechanical dysfunction found in schoolboy rugby players.
- To test a neck rehabilitation programme for strengthening the neck muscles as well as to maintain biomechanical function of the cervical spine.

1.10.3 Secondary Aims

To find a possible correlation between these specific factors as possible predisposing factors for cervical biomechanical dysfunction:

- posture,

- playing position,
- years participating in playing rugby
- anthropometric measurements,

1.11 Methodology

The method of research will consist of a review of relevant literature and an empirical investigation.

1.11.1 Literature review

The literature review will include electronic media searches using search engines such as “Medline”, “MedlinePro”, “Pubmed” as well as “Science Direct”. A library search will also be performed. Key words to be included in the search will be: rugby, neck injuries, biomechanical dysfunction, motion segment analysis, cervical spine, biomechanics cervical spine, radiography cervical spine and treatment of cervical dysfunction.

1.11.2 Empirical Investigation:

1.11.2.1 Study Design

The study design used will be a four group experimental design with three pre-test - post-test groups and a control group. The selected subjects will be evaluated for biomechanical dysfunction and will then be assigned to the different study groups.

E ₁	Y ₁	X ₁	Y ₂
E ₂	Y ₁	X ₂	Y ₂
E ₃	Y ₀	X ₂	Y ₂
C	Y ₁	--	Y ₂

1.11.2.2 Population and Sample

The study population will consist of schoolboy rugby players between 15 and 18 years of age from designated state run high schools in the Ekurhuleni Metro, Gauteng Province. The sample will be a non-probability sample with subjects being selected from rugby playing high schools in the selected region, willing to participate in the study. Considering a 95 % confidence level and a 40% improvement in the number of players with cervical biomechanical dysfunction, the sample size of each group is suggested to be approximately 25 subjects for results to be considered statistically significant.

1.11.2.3 Measurement Instruments

A physiotherapeutic evaluation technique and x-ray imaging of the cervical spine will be used to obtain the required data to be used in this.

1.11.2.4 Procedure

The study will include 4 groups of players and all subjects will undergo x-ray examination of their cervical spines. For the experimental groups three sets of x-rays will be performed. The first prior to the start of the interventions, the second following the interventions and the third 12 weeks after starting the neck rehabilitation programme. X-ray investigation of the control group will be 12 weeks apart during the 2004 rugby season.

The effectiveness of the manual physiotherapy evaluation technique in the evaluation of the biomechanics of the motion segments of the cervical spine will thus be determined and the evaluation findings will be verified using x-ray analysis. X-ray views will include lateral views of the neutral cervical spine as well as lateral views of the cervical spine in flexion and extension. The emphasis will be on the analysis of the intervertebral motion segment instead of pain provocative examination techniques. In the event of evaluating the cervical spine of a schoolboy rugby player, the player

may not present with any clinical symptoms of the cervical spine (Sandmark & Nisell, 1995).

Group 1:

E₁ will include subjects with cervical biomechanical dysfunction who will receive manual physiotherapy treatment, performed by a skilled physiotherapist (X₁), with the aim of restoring cervical biomechanical dysfunction.

Group 2:

E₂ will include subjects with cervical biomechanical dysfunction who will perform a therapeutic exercise programme for the correction of biomechanical dysfunction, based on manual physiotherapy techniques (X₂).

Group 3:

E₃ will include subjects without any cervical biomechanical dysfunction who will perform the same therapeutic exercise programme (X₂), to test the safety of the programme in players without biomechanical dysfunction, for possible adverse effects of the programme.

Group 4:

C will be the control group and will include subjects with or without cervical biomechanical dysfunction who will receive no intervention.

1.11.2.5 Statistical Analysis

Descriptive and inferential statistics will be used to analyse the data.

1.12 Relevance of the Study

The relevance of this study is equally focused on the profession of physiotherapy and the secondary school educator namely to underpin the importance of developing management programmes which could be implemented by the physiotherapist, coach and / or educator to minimize cervical biomechanical dysfunction of schoolboy rugby players. These management programmes include a validated physiotherapy evaluation technique, an effective manual physiotherapy treatment technique, and a therapeutic exercise programme to minimize or correct potential cervical biomechanical

dysfunction of the schoolboy rugby player which may eventually cause serious physical consequences. An added outcome of this study is the establishment of normative values for motion segment analysis of the cervical spine which may be used by a health care professional in x-ray analysis of the cervical spine. The educational role of the school will be of fundamental importance to ensure compliance of these programmes as well as facilitating a neck rehabilitation programme developed by the researcher.

1.13 Operational Terms

MOTION SEGMENT

This is the smallest segment in the spine that exhibits biomechanical characteristics similar to those of the entire cervical region of the spine. It consists of two adjacent vertebrae and their connecting soft tissue structures.

CERVICAL BIOMECHANICAL DYSFUNCTION

For optimal biomechanical function each motion segment of the cervical spine must have the ability to move freely within the three planes of space. Any restriction to this normal movement could be termed biomechanical dysfunction and for this study relating to the cervical region of the spine.

MANUAL PHYSIOTHERAPY EVALUATION TECHNIQUE

Manual physiotherapy evaluation techniques are assessment tools intended to aid in the diagnoses of various neuromusculoskeletal conditions clinically seen by the manual physiotherapist. This study will investigate an evaluation technique intended to identify possible restrictions of the motion segments of the cervical spine. None of the evaluation techniques currently used in vertebral motion segment analysis are as yet validated. This specific evaluation technique will be explained and tested by the researcher and thus could provide a dependable and consistently reliable evaluation

technique in the identification of cervical biomechanical dysfunction in schoolboy rugby players.

MANUAL PHYSIOTHERAPY TREATMENT TECHNIQUE

The treatment principles used by manual physiotherapists include the use of techniques such as massage, mobilisation-with-movement, vertebral mobilisation and therapeutic exercise. These treatment techniques are of great value in the treatment of a wide range of neuromusculoskeletal disorders and in patient rehabilitation. In this study a specific manual physiotherapy treatment technique will be detailed and tested for the correction of biomechanical dysfunction within the cervical region of the spine.

THERAPEUTIC EXERCISE PROGRAMME

It is of fundamental importance to develop and implement a validated therapeutic exercise program for a group of schoolboy rugby players which could be used instead of the manual physiotherapy treatment for the correction of a cervical biomechanical dysfunction. The researcher applied the same principles as for the manual physiotherapy treatment regimen. The therapeutic exercise programme is intended to be facilitated and managed by the skilled educator or coach and was specifically included in the study for the benefit of those players who do not normally have access to physiotherapy support. It also forms one aspect of a comprehensive rehabilitation programme.

NECK REHABILITATION PROGRAMME

Rehabilitation could be defined as the restoration of an individual or a part of the body to normal or near normal function after disabling disease, injury, addiction, or incarceration (Mosby's, 1994:1345). In this thesis the term "neck rehabilitation" is used to describe the programme which would achieve the optimal neck function necessary for the schoolboy rugby player. A comprehensive neck rehabilitation programme contains various elements such as strength, flexibility, mobility, stability, etc, which will be described in the text of the thesis.

1.14 Summary

In this chapter the motivation for this study was outlined. Relevant research questions as well as aims and objectives for the study were given. Chapters 2 to 5 will review the literature related to the study. Very little evidence based research could be found in the literature concerning the physiotherapeutic or therapeutic exercise management of cervical biomechanical dysfunction. The researcher emphasised the available evidence based research reviews to facilitate the theorising of the techniques used for the study. In chapter 6 the details of the empirical study will be discussed. Chapter 7 contains the results and discussion of the results of the study and chapter 8 will include a summary, conclusions and recommendations following the study. Limitations of the study will also be included in the last chapter.

Chapter 2

Literature review

2.1 Aim of the Literature Review Chapters

The aim of these chapters will be to review the relevant literature identified by the researcher to be related to the aims of this research project. Topics to be included will be the methodology of the literature review, types of tissues, biomechanical principles, biomechanically relevant anatomy of the cervical spine, a brief history of rugby, general background of rugby injuries and mechanisms of injury to the cervical spine and the role of education in the principle of self efficacy of schoolboy rugby player.

2.2 Methodology of the Literature Review

A literature review using an electronic Medline search (BioMedNet, 2003), Sciencedirect and Pubmed was conducted. The search included all articles up to 2004 and the search was not limited as far as language was concerned. Keywords used in the search were:

- Rugby/football injuries
- Biomechanics of the cervical spine
- Motion analysis of the cervical spine
- Biomechanics and rugby
- Biomechanics and sport
- Prevention of cervical spine injuries
- Schoolboy / adolescent sport injuries
- Whiplash injuries
- Motor learning
- Physiotherapy evaluation of cervical motion segments.

- Postural control.
- Schoolboy rugby injuries.
- Human movement science.
- Rugby education.

In addition a manual search in the library at the Faculty of Health Sciences of Pretoria University as well as the Northwest University PUK campus was also conducted. Various textbooks on biomechanical principles and orthopaedic assessment specifically focusing on biomechanics of the cervical spine and cervical spine injuries in rugby were also reviewed. The Harvard reference method was used (Van der Walt, 2004).

2.3 Introduction to the Literature Review

Participation in physical activity and sport is often recommended as a means of reducing many of the health risks associated with modern sedentary lifestyles. This can be summarised in a quote from Hippocrates, the father of medicine, as we know him today: “all parts of the body which have a function, if used in moderation and exercised in labours to which it is accustomed, thereby become healthy and well-developed: but if unused and left idle, they become liable to disease, defective in growth and age quickly. This is especially the case with joints and ligaments if one does not use them” (Whiting & Zernicke, 1998:5).

Leonardo da Vinci (1452 – 1519) one of the best known figures of the Renaissance was intrigued by pain and trauma. He deduced that joints act as shock absorbers since landing on the heels is much more painful than landing on the toes. He said “that which gives more resistance to a blow suffers most damage” (Whiting & Zernicke, 1998:4).

An important negative component of physical fitness is the possibility of injury sustained during participation (Waller *et al*, 1994). Some people will be at greater risk of injury than others depending on the career or sport they choose. Neuromusculoskeletal injuries have occurred since ancient times. Evidence of lesions

in the vertebrae of fossilized dinosaur vertebrae, as well as evidence of fractures of bones and joint degeneration in skeletal remains of the earliest humans has been found (Whiting & Zernicke, 1998:4).

2.4 Young People and Physical Activity

As young people grow they also mature and although these concepts are interrelated they are probably under separate genetic regulation. Maturation refers to the tempo and timing of progress towards the mature biological state. For example, sexual maturity is reproductive capability while the fully ossified skeleton is a sign of skeletal maturity. Growth refers to an increase in the size of the body or a particular area of the body. Variations in growth and maturity have profound effects upon aspects of physical activity, physical fitness and physical performance (Armstrong & Welsman, 1997:3).

Chronological age is often used as a point of reference for growth and maturation but the fact is that biological development does not occur according to a calendar (Armstrong & Welsman, 1997:4). There is a lack of standardized, valid and reliable methods of assessing anaerobic performance in young people. Cardiovascular and pulmonary responses to exercise in children and adolescents appear typically different from adults, although methodological constraints have hindered the precise quantification of measures, such as cardiac output and stroke volume. Muscular strength in boys increases linearly with chronological age from early childhood until approximately 13-14 years of age. Thereafter there is a marked increase in strength into the early or mid-twenties (Armstrong & Welsman, 1997:139). In common with other performance measures, muscular strength is highly correlated with body size (Armstrong & Welsman, 1997:40). Growth of muscle tissue during childhood and adolescence is characterised by constancy in the number of fibres, an increase in fibre size and the number of nuclei, and increase in overall muscle mass (Armstrong and Welsman, 1997:141).

Computer use is now ubiquitous in modern societies, for example, in Australia in 2000 66 % of adults used a computer. Computer use is also age related with 100 % of

senior school children in Australia using a computer (Australia Bureau of Statistics, 2000a and 2000b). The increased use of computers has been associated with an increase in reported neuromusculoskeletal disorders. The first risk is from the direct physiological and biomechanical stresses associated with interaction with current computing technology. The second risk is from the displacement of postural variability with sustained postural sedentary activities.

One may argue that a schoolboy rugby player is subjected to intense training during the rugby season and therefore not at risk for developing neuromusculoskeletal disorders caused by a sedentary lifestyle. This is however not always the case. Some schoolboy rugby players do not participate in any form of sport when the rugby season is over. Furthermore, rugby places added stresses on the neuromusculoskeletal system because it is an intense physical contact sport. Regular activity is thought to increase muscle and bone strength and enhance psychological well being (NCHS, United States of America National Centre for Health Statistics, 2000). Skilled physiotherapists are well positioned not only to prevent / decrease symptoms of computer related neuromusculoskeletal disorders, but also to promote the appropriate use of computers, as well as to encourage moderate to vigorous physical activity using large movements that require the activation of large muscle groups.

According to Starker (2004) the incidence of first occurrence of neuromusculoskeletal disorders are increasingly experienced during the teens.

2.4.1 Schoolboy Rugby Players and the game of Rugby

Rugby is a full contact sport with intermittent high intensity activity, which combines a unique blend of aerobic, anaerobic and strength requirements. Consequently the risk of injury has always been high and is becoming more of an issue due to the increased competitiveness of the game.

2.5 Rugby

2.5.1 Brief History of Rugby

Dobson and Van der Merwe researched the early history of rugby (Noakes & Du Plessis, 1996:9). They concluded that all field games played between goalposts, including rugby, soccer and hockey, could be traced back to a common medieval English ancestor. Villagers from two villages would meet half way between their villages and the aim of the game was then to transport a ball, or similar object, through the doorway (goalpost) of the home of one of the village's leaders. The game was first confined to playing fields at various English public schools during the 19th century, especially at Rugby, Westminster, Eton, Marlborough, Winchester, Charterhouse and Cheltenham. There was no uniform game between these schools and each school developed its own characteristics for the game. In 1863 a distinction between rugby and soccer was established. A detailed description of the game was first published in 1846 and was titled *Laws of football as played at Rugby School*. In 1875 in a game between Oxford and Cambridge teams were reduced from 25 or more players to 15 players. The team consisted of 10 forwards, two attacking half-backs and three defensive backs. From 1883 passing between the back-line players was permitted and the number of back-line players was increased to seven, which is still the case today.

2.5.2 Rugby Injuries

Rugby injuries are a major concern to the rugby fraternity especially when it involves schoolboy rugby players. The causes for rugby injuries could broadly be divided into intrinsic and extrinsic factors. Intrinsic factors are individual biological and psychosocial characteristics which may predispose a player to sustain a neuromusculoskeletal injury (Taimela *et al*, 1990). Intrinsic injuries may occur due to a structural or functional biomechanical abnormality within the body, which if left untreated, could result in overuse injuries. It is possible that this group of injuries will

become more frequent as players participate in pre-season and in-season training programmes (Noakes & Du Plessis, 1996:47).

5.2.2.1 Intrinsic Factors in Rugby Injuries

Many of the injuries occurring during a rugby match or practice session involve the muscles, tendons, ligaments and joints and could possibly lead to early degeneration of these structures (Lee *et al*, 2001). These degenerative changes could take up to 20 years to develop into clinical symptoms and it is therefore important to periodically follow up compromised players. A study by Lee *et al* (2001) in Scotland followed up adult players in 1998 who four years previously had sustained injuries during the 1993/1994 season. Questionnaires were posted to all injured rugby players requesting information on all injuries sustained the subject's current participation in sport and the reasons for cessation of play if applicable. Twenty five percent of players stopped playing rugby within two years of sustaining a serious musculoskeletal injury. It is therefore important to focus on the prevention of injuries as well as the correction of biomechanical dysfunction in the schoolboy rugby player so that he will not suffer the consequences of his injuries and biomechanical dysfunction later in life.

The scope of this study is not to indicate the reduction of cervical spine injuries, but rather to identify a possible biomechanical dysfunction that could be an intrinsic predisposing factor for cervical spine injury. Drs. T.D Noakes and W. Diesel, former physiotherapist for the national rugby team, at a seminar held in Cape Town, South Africa in 2002, which was also attended by the then Minister of Sport Mr. N. Balfour, suggested that there may be an intrinsic factor which predisposes a player to injury (personal correspondence).

In a study it was found that 80 % of schoolboy rugby players who were evaluated had a biomechanical dysfunction of their cervical spine without any pain or history of previous injury (Steyn, 2002). The first step in the prevention of cervical spine injuries would be to find a reliable, cost effective way of correcting this dysfunction, to implement this programme to all schoolboy rugby players and then finally to monitor the effect of such a programme in a long term follow-up study. The

establishment of a national register for cervical spine injuries in South Africa, as available in other countries, for example the USA, is also very important.

The correction of this dysfunction may ultimately reduce the early degenerative changes found in the cervical spines of rugby players. The selected group of schoolboy rugby players will have to be followed up over the next decade and the results of x-ray findings could then be compared with those in the study by Scher (1990) (Chapter 1:8). Clinically the response from old rugby players who suffer from neck pain, when asked about the incident which may have initiated the symptoms, reply that they are unaware of any specific incident, but that the symptoms had an insidious onset over many years and most of them give rugby as the cause of their symptoms (Scher, 1990).

5.2.2.2 Extrinsic Factors in rugby injuries

Extrinsic factors are independent of the injured player and are in the main related to the type of activity or surrounding circumstances during the incident of injury such as external mechanisms which could act on the body, for example a player being tackled by an opponent (Taimela *et al*, 1990).

Various studies investigating the incidence of rugby injuries concentrated on possible rule changes to prevent injuries (Micheli & Riseborough, 1974; Roy, 1974; Weightman & Browne, 1974). Most of the attempts and suggestions for reducing cervical spinal cord injuries focused on the reduction of external factors leading injuries of rugby players. Traditionally the scrum has been considered as the most obvious reason for cervical spine injuries and accordingly rule changes for the scrum were implemented. The overwhelming contribution of the tackle to injury episodes could reflect recent rule changes that encourage open play conducted at high speeds to enhance the game as a flowing spectator sport. The challenge now is to sustain the popularity of the game while reducing the hazard of high-velocity contact of the tackle (Garraway & Macleod, 1995). Studies that proposed rule changes for scrumming and strict enforcement of the high tackle rule have not significantly reduced the incidence of injury to the cervical spine.

These risks in the game of rugby resulted in an increasing number of parents to refuse to allow their children to participate in the game. The need to investigate ways of reducing or preventing injuries is therefore of paramount importance to ensure that rugby continues to develop as a popular spectator sport in South Africa. Furthermore it is important to teach schoolboy rugby players to take responsibility for protecting themselves from injury by providing them with an effective programme to reduce the risk of injury of the cervical spine. The role players involved in the management of the schoolboy rugby player are therefore in an excellent position to assist in the prevention and / reduction of rugby injuries.

2.6 Role players in the Management of the schoolboy rugby player

2.6.1 Physiotherapy and other healthcare professionals

The physiotherapist skilled in sport injury management is assuming an integral role in the rugby medical team. The main aim of the management team is to allow the player to return to the game of rugby as soon as possible, and also to minimise the risk of re-injury or temporary disablement. An excellent example of this was the South African 1995 World Cup squad. Each country could select a squad consisting of 26 players from which they then selected 15 players to participate in a match. The South African squad commenced the tournament with four injured players and at the time of the final all 26 players in the squad were fit enough to be considered for selection. The medical team consisted of a team physician, physiotherapist and an applied kinesiologist as a consultant (Noakes & Du Plessis, 1996:291).

The speedy return of the player to the game has profound implications for both the player and the team management, as far as the success of the team and the financial implication are concerned. Even at school level an increasing number of private business companies are now sponsoring teams and therefore player injuries should be minimised in order to retain talent and expertise. The physiotherapist, who is trained

to assess, treat and prevent disorders of human movement, performs a key function in the return of a player to the game after an injury.

The principles of physiotherapy have been part of the healing art since the beginning of recorded time. The aim of the physiotherapist is to improve an individual's quality of life by restoring normal function, or minimising dysfunction, as well as preventing disability following disease or injury. A combination of manual therapy, movement training and physical agents are used to resolve a condition. A skilled physiotherapist will apply the appropriate treatment based on scientific and professional knowledge and specialised skills following a thorough assessment of the patient's condition. Assessment is aimed at collecting relevant information pertaining to the patient's condition as well as the patient's living and working environment. More recently the physiotherapist has also become more active in the prevention of injuries as well as in the interception of orthopaedic conditions. This is achieved by means of thorough biomechanical assessments and the timely correction of any abnormalities found (Sutcliffe, 2000).

2.6.2 Coach and other educators

The school should form an integral role in accepting responsibility to ensure as far as practically possible the safety of the learners in extra-curricular activities offered by the school. Today with the competitiveness of school rugby the coaches are assuming a more scientific approach in the training of the rugby teams, with exercise programmes and techniques for increasing amongst many others the upper body strength as well as improved coordination. The implementation of a therapeutic exercise programme for the correction of possible biomechanical dysfunction in the cervical spines of schoolboy rugby players as well as a rehabilitation programme to increase the biomechanical function and strength of the neck could therefore form part of the training session of the rugby teams. This will ensure their compliance with the programme.

The relevant biomechanical principles of the cervical spine will be explained in detail in the following chapters. This is important in order to understand the manual

physiotherapy evaluation technique in this study, since this technique has not been validated objectively in any study to date. Imaging techniques were used to objectively test indicate the effectiveness of the evaluation technique. Following this the reasoning for the corrective techniques that were used in this study will be discussed. The various possible mechanisms for cervical spine injury will also be discussed in terms of biomechanical principles as described in the literature with possible application to rugby. It will be theorised how correcting the identified cervical dysfunction may reduce the incidence of cervical spine injury in schoolboy rugby players following the analysis of the mechanism of injury. Health care professionals, the physiotherapist in particular, can be involved in any part of the prevention and treatment of neuromusculoskeletal injuries.

2.7 Summary

The chapter commenced with the aims and methodology of the literature review. An introduction on the maturation of the young person with emphasis on the schoolboy rugby player, followed by a section on rugby, rugby injuries and the role of the physiotherapist in the management of the schoolboy rugby player was also given.

It is essential to have a working knowledge of the anatomy and biomechanics of the body to apply techniques to prevent and treat injuries. It is therefore important to review the literature on the intrinsic structures and types of tissues of the body that could be injured. This will be discussed in the following chapter.

Chapter 3

Anatomy and Biomechanics Literature Review

3.1 Anatomy

A broad overview of the relevant anatomy literature will be discussed in the following section in preparation of the detailed section pertaining to the cervical spine. The various tissue types will be reviewed, followed by the section on biomechanics.

3.1.1 Types of Tissue

Tissue is classified as one of four types: epithelial, nervous, muscle and connective. The layered or columnar arrangement of the epithelial cells is mechanically weak, but has an important role in the diffusion of tissue fluids and heat as well as in bioelectrical conduction (Silverthorn, 2001:54-65).

Nervous tissue develops from the ectoderm, the layer of cells associated with the primitive amniotic cavity (sac). The basic unit of the nervous tissue is the neuron. Communication of the nervous system is essential and the neurons are adapted for this through irritability where the cells can react to chemical or physical irritants and conductivity (the ability of the nervous system to transmit impulses from one location to the other). Nerve impulses are conducted towards the cell body through dendrites and away from the cell body by a single axon. The prime function of nervous tissue is therefore not load bearing but the conduction of nerve impulses (Snell, 2001:500).

There are three types of muscle tissue and their function is conductivity and contractibility. Skeletal muscle is under voluntary control and the prime function of skeletal muscle is to generate force to maintain posture and produce body movements. Smooth muscle is generally considered not to be under voluntary control and is found in the walls of arteries, the intestinal and respiratory systems. Smooth muscle is

innervated by both the sympathetic and parasympathetic nerves. Cardiac muscle is regarded as not being under voluntary control. Cardiac muscle cells form a functional syncytium, as the cardiac tissue acts electrically as though it was a single cell (Whiting & Zernicke, 1998:17).

Tissue fluid is the filtrate of the blood and resides in the interstitial spaces. It aids in the transport of materials between the capillaries and cells in the extracellular matrix. The tissue fluid carries nutrients and oxygen to the cells on the arterial side and removes metabolic waste products by two mechanisms: firstly through removal by the blood on the venous side and secondly through the lymphatic system. If blockage occurs in the lymphatic system the tissue fluid builds up and can be seen clinically as tissue swelling (Silverthorn, 2001:459).

For the purpose of this study the following types of connective tissue will be discussed briefly as an introduction to biomechanically relevant anatomy of the cervical spine: skeletal muscle, bone, cartilage, tendons, ligaments and fascia.

3.1.1.1 Skeletal Muscle

Muscles are the prime executors in the final phase of producing movement as determined by the input from the nervous system. Contractile proteins and a network of connective tissue are the two basic elements of muscle. The basic structure of muscle is diagrammatically presented in Figures 3.1 and 3.2 (Silverthorn, 2001:348-349). Individual muscle fibres (muscle cells) are subdivided into myofibrils, sarcomeres, and finally into actin and myosin (contractile proteins). The connective tissue surrounding the muscle is called the epimysium and the bundles of muscle fibres (fascicles) are surrounded by the perimysium. Each individual muscle fibre is surrounded by the endomysium. Skeletal muscle fibres are composed of contractile proteins to form myofibrils and hundreds of myofibrils combined form a single muscle fibre.

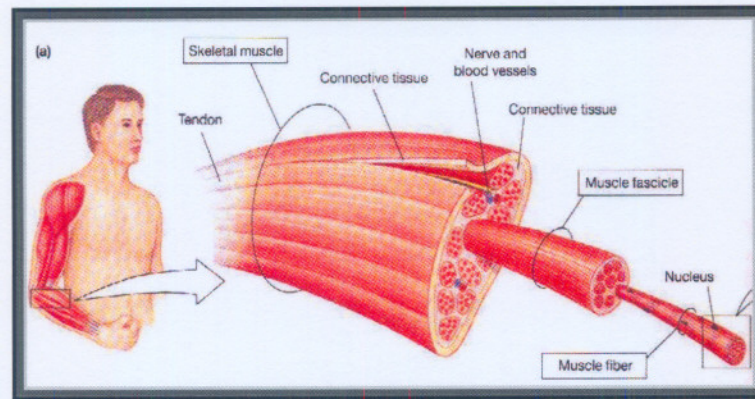


Figure 3.1: Skeletal muscle components (Silverthorn, 2001:348)

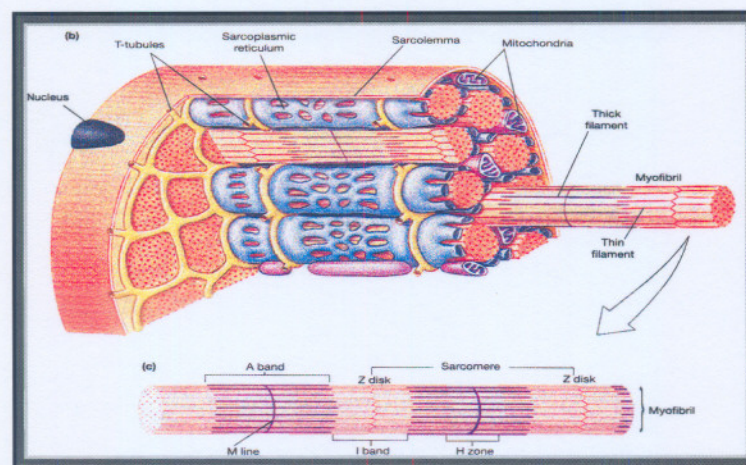


Figure 3.2: Muscle fibre components (Silverthorn, 2001:349)

Human skeletal muscle comprises several different types of fibres that have different functional characteristics. Type I muscle fibres tend to have slower contraction and relaxation times and are very fatigue resistant. Their motor unit size is typically small with a high capillary density. Type II muscle fibres can be subdivided into types IIA and IIB. Type IIA are fast twitch, fast oxidative glycolytic fibres that have high contraction speeds but are relatively fatigable, with a large motor unit size and relatively high capillary density. Type IIB muscle fibres are fast twitch and utilise glycolytic metabolic processes. They are the most fatigable but have the fastest contraction speeds and the greatest contraction strength. Their motor unit size is the

largest but they have relatively low capillary density (Per-Olof Åstrand *et al*, 2003:35).

The fundamental neuromuscular unit is the motor unit (Silverthorn, 2001:364). The motor unit consists of a motor neuron cell body located in the spinal cord, its axon, and the muscle fibres that it innervates at the motor end plates. All the muscle fibres in the motor unit contract when the neuron depolarizes. Recruiting additional motor units is the more potent mechanism for increasing the force of a muscle contraction. Once maximal motor unit recruitment is achieved, increasing the firing frequency assumes a more prominent role. In addition to the neural determinants of force, a muscle's force output is also modulated by the length of the muscle when contraction is initiated and by the velocity of the contraction. Maximum tension in the muscle is generated by an eccentric muscle contraction (muscle lengthening during contraction). Eccentric muscle contraction exceeds isometric muscle contraction which in turn exceeds concentric muscle contraction.

The terms *series-elastic component* and *parallel-elastic component* account for the passive tension properties of the muscle. These passive properties are important in muscle mechanics. Activated cross-bridges within the myofibrils resist stretching of the muscle, thus generating an internal force that is often termed muscle stiffness.

Training of specific muscle fibres results in the muscle adapting by hypertrophy. Hypertrophy is an enlargement of the individual muscle fibres, which implies an increase in contractile proteins. There is also a neurological component to strength training where the recruitment of muscles fibres through the activation of motor plates are increased and greater balance between synergists is established. The above is of utmost importance in the training programme of a rugby player's cervical spine muscles because the cervical spine muscles need to be balanced and work effectively throughout the entire physiological range of range of motion (Per-Olof Åstrand *et al*, 2003:322).

According to Whiting and Zernicke (1998:18-20) the generic components of connective tissue are cells, extracellular matrix and tissue fluid. The extracellular matrix is made up of protein fibres (collagen and elastin) and glycoproteins. More

than 30 % of the total protein in the body is collagen. The arrangement of collagen is tissue specific and can vary from loose connective tissue to highly organised parallel arranged fibres in dense connective tissue such as in tendons. The stability of collagen fibres can be enhanced by cross links both within and between collagen molecules. There are three types of collagen fibres. Type I is found in skin, bone, tendon, ligament and cornea and is the most abundant collagen fibre in the body. Type II is found in cartilage and type III is found in loose connective tissue, the dermis of the skin and blood vessel walls (Silverthorn, 2001:364 and Per-Olof Åstrand *et al*, 2003:47).

Elastic fibres are more slender and extensible. They can be stretched to 150 % of their original length before the fibre breaks. Microfibrils and elastic fibres are the two components of elastic fibres. Another component of extracellular matrix is glycoproteins. They occupy the space between the fibres and form the ground substance of connective tissues. They are negatively charged and hydrophilic (Whiting & Zernicke, 1998:22).

3.1.1.2 Bone

This specialised connective tissue is one of the hardest and strongest tissues in the body. The skeleton of the human protects the vital organs, serves as a mineral store, houses the haematopoietic cells and provides levers for muscle actions and body movements. Bone is a dynamic structure that perpetually remodels and responds to alterations in mechanical loads, systemic hormones and serum calcium levels. Bone can be classified as either cortical (compact) bone or trabecular (cancellous or spongy) bone (Silverthorn, 2001:65).

Reaching maximal potential bone mass in adolescence and early adulthood is of utmost importance for reducing the effects of bone loss later in life. The best way of achieving this is by making a lifelong commitment to vigorous weight-bearing exercise for short periods of time, instead of prolonged repetitive exercise, early in life. It is also important to gain muscle strength and to exercise the large muscle groups and to avoid periods of immobility. The nutrition of an athlete should include

foods or supplements rich in calcium, vitamin D, protein, unsaturated fats with the minimum amounts of sugar. This helps the body maintain its bone mineral content. The following five factors play a role in the relationship between physical activity and bone mass:

- Growing bone responds to low or moderate exercise through the significant addition of new cortical and trabecular bone.
- Physical activity above a certain threshold will impact negatively on some bone by suppressing the normal growth and modelling activity of the bone.
- In young adults very strenuous training may increase BMC of the tibia by up to 11 % and its bone density by 7 %.
- The long term benefits of exercise are only maintained through continued exercise.
- The amount of bone mass that can be achieved appears to depend primarily on the initial bone mass, which suggests that individuals with low initial bone mass may have more benefit from exercise (Whiting & Zernicke, 1998:97-99).

3.1.1.3 Cartilage

There are three types of cartilage namely hyaline, elastic and fibrocartilage of which hyaline is the most abundant. None of the cartilage types have intrinsic blood supply, nerves or lymph vessels and therefore cartilage cells receive their nutrients and remove metabolic waste by diffusion. Hyaline cartilage consists of collagen fibres and this gives the cartilage its tensile strength. The mechanical stiffness and strength varies throughout the cartilage with the variation in collagen fibre organisation. The perichondrium (outer fibrous and interchondrogenic layers) provides the nutrients for the cartilage except at the articular surface. The hydrophilic proteoglycans of the cartilage tend to draw fluids into the matrix but these negatively charged proteoglycans also tend to repel each other thereby creating equilibrium. Articular cartilage has a propensity to swell, but this expansion is resisted by the tensile restraint provided by the collagen fibrils. If a constant load is applied to the cartilage, it will creep (slowly deform) until a new equilibrium is reached. In adults the chondrocytes slowly continue to produce and renew proteoglycan macromolecules. With age the turnover rate of proteoglycans diminishes and some of the proteoglycan

monomers can become disconnected and this diminishes the resilience of the articular cartilage to external loads (Prentice, 2004:27).

Cyclic loading and unloading of cartilage allows for dynamic flow of fluid (with accompanying nutrients and waste products) into and out of the tissue. This is beneficial for normal matrix and cell health. Excessive loading however can be destructive to the matrix. During repeated exercise a “wear and tear” effect is seen in the cartilage. These changes may lead to osteo-arthritis. In general the earliest progressive degeneration of the cartilage takes place at the area of increased compressive load (Whiting and Zernicke, 1998:101-102).

3.1.1.4 Tendons and Ligaments

Tendons are white, collagenous flexible bands that connect muscle to bone. The insertion of the tendon to the bone involves a gradual transition from tendon to fibrocartilage, to mineralized fibrocartilage and into subchondral bone. The penetration fibres are sometimes called Sharpey’s fibres. An additional anchor is provided by fibres from the tendon, which blend with the bone’s periosteum. The myotendinous junction is a specialised region of longitudinal membranous infoldings that increase the surface area and reduce stress on the junction during contractile force transmission. The strength of the junction depends on the properties of the adjoining structures and the orientation of the applied forces. Junctions where the applied loads are shear forces are stronger than junctions where the applied forces are perpendicular to the membrane (Silverthorn, 2001:64).

Ligaments are dense, regular connective tissue structures that connect bone to bone. The primary function of ligaments is to resist tensile forces applied along the line of the collagen fibres of the ligament. The ligament’s insertion into the bone is either direct or indirect. The direct attachment is through the same specialised collagen fibres (Sharpey’s fibres) which attach tendons to bone. The indirect route is one in which the ligament blends with the periosteum of the bone. Because two thirds of the ligament is composed of water, the proteoglycans (which are hydrophilic) may play a role in the mechanical behaviour of a ligament. The joint ligaments contain several

types of sensory receptors (Ruffini corpuscles, Pacinian corpuscles, Golgi tendon organs and free-nerve endings.) that are capable of providing the nervous system with information about movement, proprioception and pain (McGinnis, 1999:233).

Ligaments act as uniaxial structures and are therefore most effective in carrying loads along the direction in which the fibres run. Their internal response, secondary to loading, is dependent on the mechanical properties of the particular ligament, which is in turn a function of its constituents. Since elastin contributes to a more mechanical elastic behaviour than collagen, ligaments with a higher proportion of elastin are more elastic (e.g. ligamentum flavum) (Yoganandan *et al*, 2001). They behave much like rubber bands in that they resist tensile forces and buckle under compression.

Tendons and ligaments respond to exercise by becoming larger and changing their material properties to become stronger per unit area (Whiting & Zernicke, 1998:105). The effect of immobilisation or disuse on ligaments and tendons are dramatic and rapid. This is however reversible with exercise, but remodelling is a slower process.

3.1.1.5 Fascia

Fascia is a term for loosely organised collagen fibres that do not fall into the pattern of tendon, aponeurosis (a strong sheet of fibrous connective tissue that serves as a tendon to attach muscles to bone or binding muscles together) or ligament. The principle fibres in fascia are collagenous, though some elastic and reticular elements also exist. Fascia is usually found in layers or in sheaths around organs, blood vessels, bones, cartilage and the dermis of the skin. It also provides firm support for muscles. Because fascia fibres lie in different transverse directions it can withstand stretching in many directions (Mosby's, 2002:659).

3.1.2. Arthrology

This is the classification of joints and joint motion. The term articulation describes the junction of two or more bones at their sites of contact. Synarthrodial (immovable) and

amphiarthrodial (slightly movable) joints do not have a cavity, while diarthrodial or synovial (movable) joints have a cavity.

Joints form *in vitro* when a group of mesenchymal cells coalesces within the developing limb to form a blastema after the appearance of the limb buds (26 – 28 day embryo). The blastema is the foundation material for the formation of the capsule, ligaments, synovial membrane and menisci of the joint. The adjacent bones are cartilage models at this stage that later undergo endochondral ossification. At this junction the interzonal mesenchyme condenses and forms an articular disc. The central cavity of the joint develops at about 10 weeks and ultimately becomes the joint cavity, which will contain the synovial fluid. The development from blastema to definable skeletal elements happens between four and 10 weeks of gestation. Many factors can influence the development of joints. Movement appears to be one of the important factors (Whiting & Zernicke, 1998:37-39). A detailed discussion on the zygapophyseal joints of the cervical spine will follow later in this chapter (Chapter 3:64)

Following this brief discussion on anatomy of the types of tissues that could be injured it is important to understand biomechanical principles that could affect the biomechanics of the cervical spine in schoolboy rugby players. Biomechanical dysfunction of the cervical spine may be an underlying cause for the development and / or recurrence of rugby injuries of the cervical spine.

3.2 Biomechanics

The term biomechanics was adopted in the 1970s to describe the science involving the study of biological systems from a mechanical perspective (Hall, 1999:32). Giovanni Borelli (1608 – 1679) is considered to be the father of biomechanics. He clearly attempted to integrate physiology and physical science. He described human and animal movement, described gait in mechanical terms and described the function of muscles according to fibre direction, fatigue and pain (Low & Reed, 1997:1-2).

The tools of mechanics, the action of forces, are used to study the functions of the human body. Both static and dynamic analyses are performed. When a system is in a state of rest or equilibrium, moving with a constant velocity, a static system is studied. When there is acceleration of the system, a dynamic system is studied. Kinematics and kinetics are subdivisions of biomechanics. Kinematics describes motions regarding patterns and speed of movement and thus describes the appearance of motion. Kinetics describes the forces associated with motion. Biomechanics is a subdivision of kinesiology, the study of human movement (Hall, 1999:3–5).

Biomechanics is also a branch of sport medicine as described by Lamb (1984) as “an umbrella term that encompasses both clinical and scientific aspects of exercise and sport”. Biomechanics could be used to improve performance through the prevention and rehabilitation of injuries, improving technique, equipment and training. A knowledge of biomechanics is useful in identifying what forces may have caused the injury, how to prevent the injury from recurring or happening in the first place and what exercises may assist in rehabilitation (McGinnis, 1999:6-12).

Biomechanics can therefore be summarised as the study of forces and their effects on the living systems, whereas exercise and sport biomechanics is the study of forces and their effects on humans in exercise and sport. Biomechanics may be a useful tool for physical educators, coaches, exercise scientists, athletic trainers, physiotherapists and others involved in human movement (McGinnis, 1999:14). The following section will describe basic biomechanical terms as a basis for understanding the biomechanically relevant anatomy and the mechanisms of injury to the cervical spine which will then be discussed.

There are three basic concepts by which all principles of mechanics can be described: length, time and mass. Isaac Newton developed a set of three laws to describe and explain the motion of objects. These three laws of Newton can be used to describe and interpret human movement (McGinnis, 1999:42–46; Panjabi & White, 2001:34-40 and Whiting & Zernicke, 1998:5–54).

Newton's first law of motion:

Every body continues in its state of rest, or uniform motion in a straight line, unless it is compelled to change that state by external forces applied to it. This law explains what happens to an object at rest or if the forces acting on the object are zero. It is commonly referred to as the law of inertia.

Newton's second law of motion:

It is commonly referred to as the law of acceleration. The change of motion of an object is directly related to the force exerted and is made in the direction of the straight line in which the force is impressed. This is the cause and effect principle. If a net external force acts on an object, that object accelerates.

Newton's third law of motion

To every action there is always opposed and equal reaction. It is commonly known as the law of action – reaction. The mutual actions of two bodies on each other are always equal and directed to contrary parts.

Another law stated by Newton is called the “*Newton's law of universal gravitation*”:

This law is divided in two parts. The first part states that objects attract each other with a gravitational force that is inversely proportional to the square of the distance between the objects. Secondly it states that this force of gravity was proportional to the mass of each of the two bodies being attracted to each other. The gravitational forces between most objects in sport are so small that one can ignore them. However the force of the earth's gravitational pull on an object is described as the weight of the object as opposed to the mass of an object (McGinnes, 1999:42–46; Panjabi & White, 2001:34-40 and Whiting & Zernicke, 1998:5–54).

3.2.1. Biomechanical Terms

The physical world can be described in terms of matter (occupies space and has mass) and energy (the capacity of a system to do work). An important concept that could be derived from the capacity of a system to do work (energy) would be force. Force is that which alters or tends to alter the state of motion of a body (Low & Reed, 1997:4).

3.2.1.1 Mass and Inertia

The property of an object to resist changes in its motion is inertia. Thus a larger object has more inertia than a smaller object. Mass is the measurement of inertia, whereas weight is the measurement of the force of gravity acting on an object (McGinnes, 1999:42–46). The concept of inertia is important in the analysis of trauma to various tissues in the body. An example is a whiplash injury of the cervical spine. The inertia of the head resists the change of the imparted acceleration of the lower cervical spine. This resistance could cause injury to the tissues of the cervical spine (Panjabi & White, 2001:35–36 and Whiting & Zernicke, 1998:45).

3.2.1.2 Force

Force is the most fundamental element in injuries. Force is defined as the mechanical action or effect applied to a body that tends to produce acceleration. The standard unit of force is newton (N), defined as the force required to accelerate a 1 kilogram (kg) mass at 1 metre (m) per second in the direction of the force. According to Whiting and Zernicke (1998:45) should an injury occur, seven factors combine to determine the nature of the injury, the tissue(s) damaged and the severity of the injury:

- Magnitude (how much force is applied)
- Location (where on the body or structure is the force applied)
- Direction (where the force is directed)
- Duration (over what time interval is the force applied)
- Frequency (how often is the force applied)
- Variability (is the magnitude of the force constant or variable over the time interval)
- Rate (how quickly the force is applied)

It does not often happen that a force acts in isolation and therefore forces causing injury or dysfunction should be viewed and considered as force systems. An example is to break the forces into force couples, which are composed of two opposite directed

parallel forces that tend to create rotation about an axis (Whiting & Zernicke, 1998:46).

3.2.1.3 Moment of Force

For linear motion, force produces the movement, while during angular movement torque produces movement. Torque is also known as the moment of force and can be defined as the effect of a force that tends to cause rotation or twisting around an axis of rotation. The mathematical definition of torque and moment is the same but technically a moment is used to describe the force creating a bending motion, while torque describes a twisting movement caused by a force. The magnitude of a torque is equal to the applied force times the shortest (perpendicular) distance from the axis of rotation to the line of the force action. This perpendicular distance is known as the moment arm, torque arm or lever arm (torque) (Panjabi & White, 2001:44).

3.2.1.4 Collisions

In many cases in musculoskeletal injuries the injury is the result of an object impacting on the body or colliding with the body. This is very frequent and relevant in rugby as rugby is a contact sport. Collisions have large forces acting over a relatively short period of time. During a collision the body undergoes deformation. In the case of two billiard balls that collide the deformation is negligible, but during a tackle the deformation can be considerable. The deformed body may experience a plastic deformation, an elastic deformation or both. In a plastic deformation the deformation is permanent and during an elastic deformation the body returns to its original state after the force is removed. The body's ability to return to its original state is called its *elasticity* and is an essential characteristic of body tissues (Whiting & Zernicke, 1998:58 and Silverthorn, 2001:63).

Most collisions involving the human musculoskeletal system are elastoplastic in nature. The tissues deform, sometimes permanently, and there is transfer and / or loss of energy in the collision (McGinnis, 1999:105). In the game of rugby collisions are frequent and probably the biggest cause of injury.

3.2.1.5 Friction

Friction is defined as the resistance created as the result of two bodies being in contact with one another. Resistance results from microscopic irregularities (asperities) on the opposing surfaces. The force of friction is usually of less magnitude applied over a long period of time. This is very apparent in micro-trauma and overuse injuries experienced by rugby players. Relatively small forces applied across the facet joints of the cervical spine during training could contribute to dysfunction developing in the cervical spine (Panjabi & White, 2001:96).

3.2.1.6 Fluid Mechanics

The resistance produced by fluids may be considered 'fluid friction' and is termed viscosity. Viscosity is the property of a fluid that enables it to develop and maintain a resistance to flow, dependent on the flow's velocity. Since all biological tissues have a fluid component, the response of the tissue to mechanical loading will include a viscous component. This is a major factor in creating stiffness in the body tissues to resist applied forces and during force transfer. This is apparent during most manoeuvres in rugby where the player is in contact with another player, or forces developed in the player's own body (Mosby's, 2002:1815).

3.2.1.7 Joint Mechanics

No two joints are the same in structural terms. Each has its unique combination of tissues, tissue configuration and movement potential. Each joint in the body has a range of motion through which the joint can normally move. Range of motion has large individual differences and thus global range of motion should not be used as a standard for every person. In the same person the range of motion can differ during different times in any day. Intrinsically related to range of motion is the stability of the joint. This is the ability of the joint to maintain stability throughout the entire range of motion. Injury occurs when the joint exceeds its normal range of motion. The joint range of motion is determined by:

- The shape of the articular surfaces and their geometric interaction
- The restraint provided by ligaments, joint capsule and other peri-articular structures
- The action of the muscles around the joint (Whiting & Zernicke, 1998:61).

When the limits of these restraints are exceeded an injury occurs. Joints can be considered as being relatively stable or unstable depending on the bony fit of the joint and the amount of ligaments and other supporting structures around the joint, such as large muscle support. In the cervical spine the joints are adapted to give maximum mobility for the head to be able to rotate in all directions while also giving stability to protect the spinal cord (Whiting & Zernicke, 1998:61). In the rugby player the strain on the cervical spine is sometimes severe, therefore the stability of their cervical spines are depended on optimal function of all the soft tissue structures surrounding the vertebrae and joint in this region.

3.2.1.8 Lever Systems

The lever systems in the body provide two important functions. Firstly they increase the effect of the applied force, because the applied force and the resisting force have two different moment arms, for example the way that leverage is gained by using a bar to pry a large rock loose from the ground. The second function is to increase the effective speed (velocity) of movement. The use of these lever systems provides the means for controlled effective movement to perform activities of daily living. The same lever systems play an important role in injury and injury prevention in for example a contact sport such as rugby (Silverthorn, 2001:367; Whiting & Zernicke, 1998:62).

3.2.1.9 Joint Lubrication

Synovial joints contain synovial fluid that is necessary for lubrication, shock absorption, and nutritive functions. The synovial fluid reduces friction in the joint to extremely low levels and plays an important role in the durability of the joint (lack of wear and tear). In the event of a hypomobile joint the joint will not move through full

range of motion, therefore the synovial fluid will not flow through the entire joint to provide nutrition to the joint surfaces (Low & Reed, 1997:107-109 and Panjabi & White, 2001:151).

3.2.1.10 Rigid-body Mechanics

In the examination of the biomechanics of injury the material properties of the various structures in the human body and their reaction to force should be investigated.

Stress and Strain

Any loaded tissue has internal resistance to an external load. Axial stresses can be divided into compressive (resistance to being pushed together) and tensile (resistance to being pulled apart). Materials change shape when subjected to external loads. This change in shape is termed deformation and is measured in mechanical strain. When the material elongates due to tensile load, it is called tensile strain. Axial compression results in compressive strain and a shear load causes shear strain (Whiting & Zernicke, 1998:68). A direct relationship exists between stress and strain and this relationship determine the tissue's susceptibility to injury. This relationship between stress and strain can be depicted on a graph to indicate the tissue's response to certain forces or loads (Panjabi & White, 2001:73). The ratio between stress and strain of a tissue can be termed the stiffness of the tissue. The opposite of stiffness is termed compliance. The mechanical response of tissue to load is not linear throughout the physiological range of motion due to the non-linear characteristics of the tissue's fluid component. Given the fact that rugby is an intense contact sport a player will be subjected to severe stress and strain loads, both external and internal in nature (Bogduk & Mercer, 2000).

Viscoelasticity

In viscoelastic tissue an increase in strain rate increases the slope of the load-deformation curve (White & Panjabi, 1990:21) and hence the stiffness of the material. Purely elastic materials store energy while being deformed and when the load is

released the strain energy is returned and the tissue returns to its original shape with no energy loss. Viscoelastic tissues lose energy to heat during deformation and their return to their original state following unloading is retarded. When tissue is subjected to constant load a viscous time dependent response is seen as the creep response. When first loaded, the tissue deforms quickly until a specific force level is reached. The tissue continues to creep as it approaches a deformation plateau. For the cervical spine of a schoolboy rugby player this is very important. The possibility exists that the ligaments and soft tissues supporting the cervical spine may undergo creep towards the end of a tough game, increasing the risk of injury (Whiting & Zernicke, 1998:76; Panjabi & White, 2001:89).

Material Fatigue and Failure

Biological tissues, subjected to repeated force above a certain threshold experience failure resulting in a decreased ability to withstand forces. Continued force application of a fatigued tissue will lead to tissue failure. The susceptibility to tissue failure is determined by how the stresses are distributed by the loaded tissue. If the stresses are evenly distributed throughout the tissue there is less chance of failure than in the event of the stresses acting on one concentrated area (Panjabi & White, 2001:167-182; Whiting & Zernicke, 1998:78).

3.2.2. Biomechanics of the Spine

Biomechanically, the human spine is a remarkable structure that must meet two seemingly contradictory requirements namely the achievement of sufficient stability and the provision of adequate mobility (Danneels & Vanderstraeten, 2004).

The focus area of the spine for this study will be the cervical spine region consisting of the first seven (C1-C7) of the 33 vertebrae. The other regions are the thoracic (T1-T12), lumbar (L1-L5), sacral and coccyx. The primary curves that are present at birth are concave anterior in the thoracic and sacral regions. As the infant develops head control and carries the weight of the head the cervical lordosis develops and when the child starts walking the lumbar lordosis develops. These curves are not present at birth

and therefore are called secondary curves. The curves of the vertebral column functions more efficiently in aiding shock absorption than a straight spine. Bones are constantly remodelling and therefore the vertebral column will adapt to asymmetrical forces by a change in the spinal curvatures, such as the development of scoliosis (Hall, 1999:292-294; Bogduk & Mercer, 2000).

The cervical spine supports the head and provides a platform to perform important sensory observations such as hearing and vision. In order to function optimally the sensory organs must be able to scan the environment and focus on the object of interest. The movements of the head are executed by the muscles, but the type of movements possible depends on the shape and structure of the cervical vertebrae and the interplay between them (Onan *et al*, 1998b). The cervical spine furthermore must protect the vital spinal cord and vertebral arteries whilst still providing sufficient stability and mobility for the head. There are three pillars that provide these functions, and they consist of the two posterior articular pillars formed by the zygapophyseal joints of the cervical spine and the third pillar formed by the vertebral bodies and discs that give anterior support. This orientation provides excellent protection for the spinal cord. The spinal cord is tethered within the dura mater by the dentate ligaments for stability. Further protection for the spinal cord is provided by the cerebrospinal fluid, epidural and extradural fat and the longitudinal ligaments of the spine (Mercer & Bogduk, 2001).

From the third to the seventh cervical vertebrae a second set of plane-type synovial joints, known as the uncovertebral joints are present. These appear as lateral lipping along the lateral edges of the superior margins of the vertebral bodies articulating with the inferior margins of the bodies of the vertebrae above. The orientation of these small joints plays a role in determining the degree and direction of movements occurring in the cervical spine (Mitchell, 1994). The lordosis of the cervical spine is due to the wedge shape of the discs and the greater anterior height of the vertebral body in this region. From C1 to L5 the volume of the vertebral bodies increases consistently (White & Panjabi, 1990:115-116).

The following section will describe in more detail how each of the biological structures that make up the cervical spine functions biomechanically and how forces

could cause failure of these structures resulting in injury. The vertebrae, intervertebral discs and spinal ligaments will be discussed in terms of physical properties as well as function and failure models.

3.2.2.1 The Vertebra

The vertebra consists of the anterior vertebral body and the posterior bony ring, the neural arch, containing the articular, transverse and spinous processes. The vertebral body is a cylindrical mass of cancellous bone contained in a shell of cortical bone. The superior and inferior aspects are slightly concave and called the vertebral end-plates. The neural arch consists of two pedicles and two laminae, from which seven processes arise. Although the shape of the vertebrae from C3 to L5 is basically the same, the size of the vertebrae increases from superior to inferior. This is the mechanical adaptation for the increase in compressive loads carried by the vertebrae from superior to inferior. In the cervical spine there are foramina for the vertebral arteries. It is important to remember that the physical properties of the vertebrae change with age (White & Panjabi, 1990:28).

The typical cervical vertebra has a small, ovoid body with the long axis transversely orientated. The left and right lateral margins of the superior aspects of the body are raised to form the uncinate processes, which relate to the bevelled surfaces on the right and left lateral margins of the inferior surface of the vertebra above (Torg, 1982:126). This resembles the bucket seat in a sports car and aids in providing stability of the cervical motion segment. Degeneration of these joints occurs after the first decade of life. The importance of these joints is that their posterior margins form the border of the intervertebral foramen and thus are in close proximity to the emerging spinal nerve and the vertebral artery as the latter passes through the foramina transversaria. Osteophytes in this region may impinge on both the nerve and the artery. The left and right transverse processes have a groove to support the spinal nerve. The transverse foramina, which transmit the vertebral artery, are far enough anterior in the roots of the transverse processes so as to place the ascending vertebral artery in front of the emergent spinal nerve. The spinous processes of the cervical vertebrae are normally bifid at their tips (Yoganandan *et al*, 2001).

Physical Properties of the Vertebral Body

Bell et al (1967) reported that a small loss in osseous tissue produces considerable loss in bone strength. A decrease of 25 % in osseous tissue produces a decrease of 50 % in bone strength. The vertebral body takes most of the strain during compression. There are conflicting results in the literature concerning the load carried by the cancellous core and the cortical shell. A study by Keller et al (1989) investigated the properties of the spongy cancellous bone of the vertebral body. Various blocks of the cancellous bone were subjected to compressive loads and the point of failure was determined. Three types of results were obtained. Type I showed a decrease in strength after the failure point while in the type II specimens the strength, after the failure point, was maintained. In the type III bodies (38 % of cases) there was an increase in strength after the point of failure. The function of the cancellous bone is therefore not only to share the load with the cortical shell, but also to act as the main resistor of dynamic peak loads during higher rates of loading (White & Panjabi, 1990:31-37).

Physical properties of the Endplate

Studies conducted to test the failure point of the vertebral endplate found that three patterns of endplate failure occurred. In the first example the centre of the endplate failed with disc herniation. This pattern of failure occurred mostly in younger specimens with no disc degeneration. If there is no degeneration in a disc the nucleus will resist compressive forces by building up pressure. The effect is tension in the peripheral annular fibres with an increase in pressure against the vertebral endplates. In the event of disc degeneration a peripheral endplate failure pattern was found. This could be explained by the fact that, with a decrease in pressure build up in the nucleus, the forces are transferred from one vertebra to the next by the annular fibres. The forces are therefore transferred to the periphery of the vertebral endplate resulting in fracture of the endplate (White & Panjabi, 1990:37-38).

3.2.2.2 The Intervertebral Disc

Three distinct parts form the disc: the annulus fibrosus, nucleus pulposus and the cartilaginous endplates. The nucleus pulposus is centrally located and is composed of a very loose and translucent network of fine fibrous strands that lie in a mucoprotein gel containing various mucopolysaccharides. The water content ranges from 70 – 90 %. The size of the nucleus and its ability to swell is greater in the cervical and lumbar regions than in the thoracic region. The intervertebral disc constitutes 20 to 33 % of the entire length of the spine (White & Panjabi, 1990:3).

The annulus fibrosus forms the outer boundary of the disc. The annulus is composed of fibrous tissue organised in concentric laminated bands. The cervical intervertebral discs differ from the lumbar intervertebral discs in that they lack a concentric annulus fibrosus around their entire perimeter. The annulus is well developed and thick anteriorly but it tapers laterally and posteriorly towards the anterior edge of the uncinate processes on each side (Bogduk & Mercer, 2000). The crisscross annular fibres as seen in the lumbar discs are absent. Instead the fibres of the anterior annulus consistently converge upwards towards the anterior end of the upper vertebra. This arrangement is consistent with that vertebra pivoting about its anterior end. In effect the anterior annulus is an interosseous ligament, disposed like an inverted “V” whose apex points to the axis of rotation. The posterior annulus is represented by only a couple of fibres near the median plane that are longitudinally oriented and gathered in a lamina only about 1 mm thick. Lateral to these fibres, as far as the uncinate process, the annulus is absent. The posterior part of the disc is only supported by the longitudinal ligament (Onan *et al*, 1998 and Mercer & Bogduk, 2001).

The cartilaginous endplate is composed of hyaline cartilage and separates the rest of the disc from the vertebral body. The endplate starts as an active growth cartilage, then changes with age into irregularly arranged growth cartilage which disappears with age and is replaced by bone (White & Panjabi, 1990:4).

The intervertebral disc has a blood supply up to the age of 8 years. After this the disc must rely on mechanical properties to maintain a healthy state. Changes in posture and body position causes pressure differences in the disc causing a pumping action in the disc. The influx and outflux of water carries nutrients and waste products to and from the disc. Therefore sustained posture, even in a perfect position will have a negative effect on the health of the disc. Injury and age have negative effects on the water absorption of the disc and result in a decrease in nutrition and shock absorption (Hall, 1999:286-290).

In adults transverse fissures develop across the posterior part of the cervical discs. These fissures commence at about nine years of age as clefts in the uncovertebral region. Progressively they extend medially across the disc, ultimately to form transverse clefts by the third decade of life. These clefts are a normal feature of the cervical discs. What is not known is if they constitute some form of programmed attrition of the posterior annulus, or they arise as a result of repeated attempts at axial rotation during early life. Whatever the explanation, their presence allows, or facilitates, axial rotation (Bogduk & Mercer, 2000).

The intervertebral disc (IVD) has many important functions in the biomechanics of the spine. In contrast to ligaments which are uniaxial, intervertebral discs respond to or experience multiple load vectors. The head is eccentrically placed with respect to the cervical column and therefore the intervertebral discs do not carry / resist pure loading. This non-central anatomy of the nucleus pulposus also contributes to the dissimilar proportions of internal load sharing by the anterior and posterior. The intervertebral discs together with the zygapophyseal joints are responsible for carrying all the compressive loads the spine is subjected to. Other stresses on the intervertebral disc are the tensile stresses produced during physiological movements such as flexion and extension. Torsion stress produces movements such as rotation of the segment. Combined movements of the spine produce compressive, tensile and shear stresses on the annulus fibrosus (Yoganandan *et al*, 2001).

Two different load situations can be described for the intervertebral discs and this is important since the IVD has time dependent properties. Short-duration, high level loads (e.g. tackling and jerk lifting) could cause irreparable structural damage when

the stress levels exceed the critical failure value of the IVD. Long-duration, low-level repetitive loading of relatively low amplitude could also cause failure due to fatigue. A small tear develops at the area of highest stress and it eventually enlarges and results in complete failure. The biomechanical behaviour of the IVD depends on the relative degeneration of the disc. The degree of degeneration is age-dependent as well as the result of injury (Onan *et al*, 1998a).

ELASTIC CHARACTERISTICS

The disc is a viscoelastic structure. It is important to distinguish between the load on the disc as a structure and the stresses produced within the disc material. An example is the compressive forces on the disc as a structure when standing upright while the nucleus pulposus is subjected to tensile stress. When experimenting with the properties of discs specimens are subjected to various stresses while deformation is recorded continuously. Most specimens are obtained from the lumbar spine with very few experiments conducted on the discs of the cervical spine (White & Panjabi, 1990:4).

COMPRESSION

A load (y – axis) and deformation (x – axis) curve has been found useful to in documenting the physical properties of the specimen. With the application of compression typically the load – displacement curve is of a sigmoid type, with the concavity initially towards the load axis, followed by a straight line and then the convexity towards the load axis in the final phase just prior to failure. Such a curve implies that the disc provides very little resistance at low loads. When the load increases the disc becomes stiffer. This means that the disc is flexible at low loads and stable at high loads.

Virgin (1951) showed that, even with permanent deformation due to compressive forces to the disc, there was no herniation of the nucleus pulposus despite the fact that an incision was made through the annulus fibrosus to the centre of the disc. This phenomenon was also demonstrated by Hirsch (1955) and Markolf and Morris (1974) more than a decade later. When the functional spinal unit without the posterior

structures was subjected to compression forces, the unit failed due to fractures of the vertebral endplate but there was no failure of the disc (Brown *et al*, 1957).

A study by Farfan (1973) showed that a degenerated disc is even stronger than a normal disc. When a degenerated disc is subjected to compressive forces the nucleus pulposus herniates into the vertebral body through the vertebral endplates and resembles Schmorl's nodes. When central compressive forces are applied to a normal disc the disc bulges in a horizontal plane, but not in any particular direction. The clinical observation that a disc herniates in a posterior-lateral direction could therefore not be explained by pure compressive loading, but rather as the result of combined forces (White & Panjabi, 1990:4).

TENSILE PROPERTIES

The disc is seldom subjected to tensile stress during normal physiological conditions. Even when traction is applied to the spine the disc is under compressive stress due to the muscle reaction around the motion segment. However, the annulus fibrosus is subject to tensile stress during physiological movements. With flexion the instantaneous axis of rotation lies in the frontal and transverse planes and passes through the middle of the disc. Therefore in flexion the posterior part of the annulus is subjected to tensile stress. The opposite is true for extension. With lateral bending the convex side undergoes tensile stress and with rotation the tensile stresses develop at about 45° to the disc plane (White & Panjabi, 1990:4). A study by Brown *et al* (1957) indicated that the anterior and posterior parts of the disc are stronger than the lateral sides and that the centre of the nucleus pulposus is the weakest.

BENDING CHARACTERISTICS

Removal of the posterior elements of the functional spinal unit resulted in the failure of the disc with 15° of anterior flexion. A triangular piece of bone was avulsed from the postero-inferior aspect of the superior vertebra (Brown *et al*, 1957). Roaf (1960) noticed that the bulging of the annulus is always on the concave side of the curve and that denucleation seemed to increase bulging. He also found that on flexion and

extension the nucleus does not change shape or position (Figure 3.3, White & Panjabi, 1990:15)

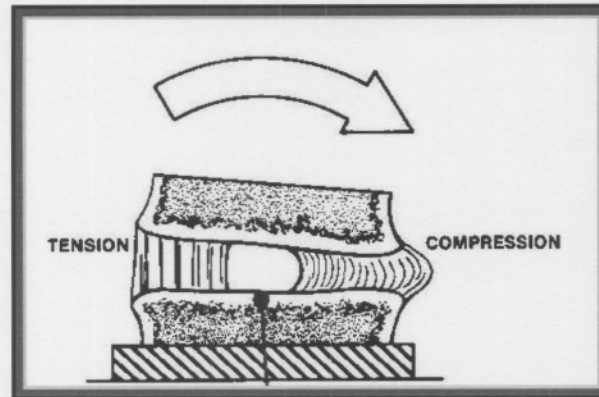


Figure 3.3: Bulging of the annulus fibrosus on the concave side of the bending curve (White & Panjabi, 1990:15)

TORSIONAL BEHAVIOUR

Farfan (1970) tested 21 nondegenerated and 14 degenerated lumbar discs *in vitro* and applied torsion to the disc with the axis passing through the posterior part of the disc. He found that the degenerated discs failed 25 % earlier than the nondegenerated disc. In the initial phase 0° - 3° of deformation occurred with very little torque. Between 3° - 12° a linear relationship between torque and deformation was found and failure occurred at approximately 20° of rotation.

SHEAR CHARACTERISTICS

Failure due to pure shear force in the horizontal plane is very high at 260 N/mm. This high value is clinically significant since a very large force is required to produce abnormal horizontal displacement of the vertebral disc unit. Therefore annulus disruption is most probably the result of combined bending, torsion and tension forces (White & Panjabi, 1990:9).

VISCOELASTIC CHARACTERISTICS:

The physical properties of a structure that documents its time-dependent behaviour are called its viscoelastic properties. For example, if the elastic tests were repeated at faster loading speeds, the load – displacement curves would be different. In fact, they would exhibit stiffer behaviour. The terms creep, relaxation and hysteresis are used to describe the viscoelastic properties of a structure (Panjabi & White, 2001:89).

CREEP AND RELAXATION

Markolf and Morris (1974) studied creep under the application of three different loads *in vitro* and made observations for up to 70 minutes. Higher loads produced greater deformation and faster rates of creep. Kazarian (1975) performed compressive creep tests on functional spinal units (FSUs) with different stages of degeneration. He observed that the shape of the curves and the degeneration of the discs are related. The nondegenerated discs creep slowly and reach final deformation after considerable time compared to the degenerated discs. The process of degeneration therefore makes the disc less viscoelastic. This implies that as the disc degenerates it loses its capability to attenuate shocks and to distribute loads evenly over the entire endplate.

HYSTERESIS

All viscoelastic structures exhibit hysteresis. It means that when structures is subjected to repetitive load and unload cycles a loss of energy occurs (Mosby's, 2002:860). This could be considered a protective mechanism for example when a person jumps up and down the shock is absorbed by the disc and vertebrae from the feet to the brain because of hysteresis. Hysteresis is dependent on the load applied and the age of the disc. The higher the load the more the hysteresis. Hysteresis is largest in young people and smallest in the middle-aged (Virgin, 1951). It was also observed that hysteresis decreased if the disc was loaded a second time. This may imply that one is less protected against repetitive load. This is clinically relevant for a rugby player since the player's spine is subjected to repetitive high loads especially in a match situation.

FATIGUE TOLERANCE

It is important to establish the number of load cycles a disc can tolerate before radial and circumferential tears develop since the disc's biological capacity for healing is low. Brown et al (1957) performed an *in vitro* experiment where a single disc was subjected to a small constant axial load and a repetitive forward bending motion of 5°. The disc showed signs of failure after only 200 cycles of bending and complete failure occurred at 1000 cycles. The fatigue tolerance *in vivo* is not known (White & Panjabi, 1990:10).

Intervertebral Disc Function after Injury

Earliest studies showed that the function of the disc is not affected by injury, implying that a sort of 'self sealing' occurs after an injury (Markolf & Morris, 1974). Recent studies refute this and show that injury does indeed affect the mechanical properties of the disc. A study by Panjabi et al (1984) used dissected lumbar functional spinal units (FSUs) with the posterior elements intact. A square was removed surgically from the posterolateral part of the disc annulus and then the nucleus pulposus was removed. The specimens were tested before and after each of the two injuries. Significant changes in both the main and coupled motions were observed. The motions most affected were flexion, lateral bending and traction and even more so after the second injury. Compression was least influenced. The changes that do occur are not symmetrical to the sagittal plane. The authors hypothesise that the asymmetric motion at one joint may lead to adaptive changes of the joints superior and inferior to the affected joint (White & Panjabi, 1990:15).

When the stress at any point in a structure exceeds the strength of the tissue at that point, the tissue fails. Normally mathematical models are used to measure the stresses inside a structure and the most frequently used model is called the Finite Element Method. The model by Shirazi-Adl et al (1984) is the most comprehensible to date. It simulates the L2-L3 motion segment with appropriate stiffness values and the model has been validated by actual direct measurement parameters. Up to approximately 30 years of age the nucleus pulposus has sufficient water content to act like a gelatinous

mass. As load is applied pressure builds up inside the nucleus and pushes the surrounding structures away from the nucleus centre. This implies that the central portions of the two vertebral endplates are pushed away from one another and that the annular ring pushes radially outward. In the degenerated disc the response to compression differs because of the fact that the nucleus is not capable of producing sufficient fluid pressure. The result is that the endplates are subjected to less pressure, and therefore the pressure is distributed more evenly throughout the annular ring.

The following is a brief explanation of tension, bending, torsion and strains in annular fibres as discussed by White and Panjabi (1990:15-16).

TENSION:

Based on reviewed literature a detailed computer analysis of the human disc under tensile loading has as yet not been carried out. The alternating layers of the annular ring absorb compressive forces very well but this fibre orientation does not resist shear stresses very well. The risk of disc failure is therefore increased with tensile loading compared to compressive loading. During tensile loading the horizontal dimensions of the disc is also altered. Because of Poisson's effect, the disc bulges during compression and contracts in tension (White & Panjabi, 1990:15).

BENDING

During bending in any direction the convex side of the spine is subjected to tension, and therefore the disc on that side is subjected to tensile forces. On the concave side the spine is subjected to compression and therefore the disc on that side of the spine is subjected to compressive forces. Therefore during bending one can reason that the disc is subjected to a combination of tensile and compressive forces. The forces that the annular ring is subjected to increases from the inside out, therefore the magnitude of the forces on the outer layers is larger than on the inner layers (White & Panjabi, 1990:15).

TORSION

When the disc is subjected to axial torque the stress depends on the degree of degeneration of the disc. The stress was found to be greater in the anterior part of the disc in all cases. The posterior and posterolateral parts of the disc were stressed in both left and right rotation. Removal of the posterior elements increased the stresses in all fibres. Loss of intradiscal pressure decreased the stress while the addition of compressive loads did not alter the stresses significantly (White & Panjabi, 1990:16).

SHEAR

Shear stresses have not been studied in a mathematical model, but simple free body analysis indicates that shear stresses are equal in magnitude over the annulus and zero on the surface. Stress increases towards the centre, parallel to the applied shear force. There may also be tensile and compressive stresses at approximately 45° to the transverse plane (White & Panjabi, 1990:15).

Strains in Annular Fibres

Compared to stresses strains can be experimentally measured. This is usually performed in a vertebra-disc-vertebra specimen with the posterior elements removed. Microphotographic targets are glued onto the surface of a single annular fibre from one endplate to the other. Using stereophotogrammetric methods, three-dimensional measurements of the distance between the adjacent targets are measured. The fibre strains were found to be less than 3 % when subjected to compressive loads. Under torque the strain was considerably greater at 9 %. This indicates that compressive loads of the spine are probably carried by the nucleus and inner annular fibres. This also supports the theory that annular fibres may be torn by torsional loads (Yoganandan *et al*, 2001).

Disc Bulge

The clinical observation of nerve root irritation caused by disc bulge led to several studies which observed and measured disc bulge. Specimens without posterior elements were used in most of the studies. The largest disc bulge was measured in the mid-disc plane when the FSU was subjected to simultaneous compression and lateral bending. The disc bulged most in the lateral and posterolateral region on the concave side of the discs. This value increased by more than twice in the case of a degenerated disc. The disc bulge increased following fracture of the vertebral endplates (Brinckmann, 1986).

Internal Deformation of the Disc

Krag et al (1987) performed a study where they implanted small steel balls into the FSU of L4-L5. Lateral x-rays were taken in various physiological movement positions. In compression all the balls moved anterior. During flexion the nucleus moved posterior and the annulus moved anterior. In extension the opposite took place. Following the removal of the nucleus pulposus the displacement of the internal wall of the annulus was always towards the centre of the disc, especially for the anterior portion of the annulus. This held true for compression and flexion, despite the outward bulge of the disc. This finding therefore contradicts the suggestion that extension exercises improves posterior disc bulge following disc herniation.

Mechanism of Disc Prolapse

From the previous discussions it is seen that the posterolateral disc prolapse clinically most often seen could not be simulated by the various experiments. A study by Adams and Hutton (1982) showed that with sudden impact combined with lateral bending and flexion, so that the posterolateral fibres of the annulus were under tension, when sudden compression was added a disc prolapse in 26 of the 61 dissected specimens tested took place. The specimens that failed were from spines with grade 2 degeneration as generally found in the age group between 40 and 50 years. With gradual loading of the specimens in flexion lateral bending and axial compression

loading a disc prolapse did not occur. The conclusion of these authors was that gradual disc prolapses were the result of a combination of factors, such as a weakened posterior annulus fibrosus, relatively non-degenerated nucleus with degenerated annulus that had developed fissures, and another kind of loading such as bending and twisting.

3.2.2.3 Spinal Ligaments

Nature has designed the spine in such a manner that when the motion segments or functional spinal unit (FSU) is subjected to different complex force and torque vectors, the individual ligaments provide tensile resistance to the external loads by developing tension (White & Panjabi, 1990:18 and Torg, 1982:129-131).

Ligaments of the spine have the following functions:

- They allow adequate physiological movement and fixed postural attitudes between vertebrae, with the minimum expenditure of muscle energy.
- They protect the spinal cord by restricting movement within well defined limits.
- Ligaments together with the muscles share the role of providing stability to the spine within its physiologic ranges of motion.
- They protect the spinal cord in traumatic situations where high loads are applied at fast speeds. In these highly dynamic situations the displacement must be restricted within safe limits and the large amounts of energy that are suddenly applied to the spine must also be absorbed.

The function of a ligament is also dependent on the location of the instantaneous axis of rotation. Shifting the axis of rotation will change the lever arm. This implies that the function of the ligament can change during different movements of the spine and even during the same movement as the centres of rotation changes. Initially there is very little force required for movement of the spine. This means that for normal the physiological movement the minimum amount of energy is used. Towards the end of physiological range of motion there is a sharp increase in stiffness. In the trauma range there is 77 times increase in stiffness than in the normal flexion range.

Therefore the two functions required by ligaments are accomplished by the shape of the load-deformation curve. When large flexion loads are applied to the spine in a traumatic situation the shape of the load-deformation curve is such that a large amount of energy is absorbed before failure. Nearly seven times more energy is absorbed during a traumatic situation than during normal flexion. The ligaments of the upper cervical spine differ from the ligaments found from C2 to the sacrum. (Panjabi & White 2001:177-179).

The *anterior longitudinal ligament* arises from the anterior aspect of the basiocciput and is attached to the atlas and the anterior surface of all the vertebrae, including part of the sacrum. It is firmly attached to the edges of the vertebral bodies, but not so firmly to the annular fibres of the disc.

The *posterior longitudinal ligament* arises from the posterior aspect of the basiocciput, covers the dens and the transverse ligament (called the membrane tectoria) and runs over the posterior surfaces of all the vertebral bodies to the coccyx. It is interwoven with the intervertebral disc and wider at the disc level than the vertebral body level.

The anterior and posterior longitudinal ligaments deform when the vertebral bodies separate during movement as well as when the disc bulges. Traction on the attachment areas of the ligaments on the vertebral bodies may produce 'anterior lipping' as seen clinically on x-rays. Roaf (1960) claimed that one cannot disrupt the longitudinal ligaments by flexion or extension of the spine but that this can occur with rotation. Tkaczuk (1968) studied the characteristics of the longitudinal ligaments with age and found that all the biomechanical parameters of the ligaments decreased with degeneration. The most marked decrease was the energy absorption properties of the ligament. This implies that the shock absorption properties of ligaments decrease with age. The anterior longitudinal ligament is twice as strong as the posterior longitudinal ligament but their material properties are the same.

The *capsular ligaments* are attached just beyond the margins of the adjacent articular processes. The fibres are orientated to the plane perpendicular to the plane of the zygapophyseal joints. They are shorter and more taut in the thoracic and lumbar

regions than in the cervical area. Therefore this allows more movement in the cervical spine. The capsular ligament provides stability in flexion in the cervical spine (Panjabi *et al*, 1975).

The *ligamenta flava* extend from the antero-inferior border of the laminae above to the posterosuperior border of the laminae below, connecting the borders vertebrae from the second cervical vertebra to the first sacral vertebra. The ligament is composed of a large amount of elastic fibres and is one of the most elastic structures in the human body. With ageing there is an increased amount of fibrous tissue.

The ligamentum flavum is in a pre-tensing condition when the spine is in neutral position. This means that there is 'resting compression' in the disc. The resting tension decreases with age. The function of this resting tension could be why the ligament does not protrude into the spinal canal during full extension (Nachemson & Evans, 1968). The fact that the ligamentum flavum is the most elastic ligament in the body means that the ligament undergoes the least deformation due to tension; thus when the spine moves from full flexion to full extension the elasticity of the ligament, together with the pre-tension, minimizes the chances of impingement of the spinal cord.

The *interspinous ligament* connects adjacent spinous processes and its attachment extends from the root to the apex of the spinous process. They are broader and thicker in the lumbar region but only slightly developed in the cervical spine.

The *supraspinous ligament* originates in the ligamentum nuchae and continues along the tips of the spinous processes as a round, slender strand down to the sacrum. It is thicker in the lumbar region.

Because the interspinous and supraspinous ligaments are closest to the skin these were the first ligaments to be tested *in vivo*. The tension was measured by placing pins in these ligaments. The amount of sideways movement of the pin was taken as measurement of tension in the ligaments. The tension slowly increased as the spine was flexed, reaching maximum tension with full flexion (Nachemson & Evans, 1968).

The strength of a ligament is important during spinal trauma. Another important characteristic of the spinal ligaments for physiological function is the non-linear load-displacement curve. A load-displacement curve of typical spinal ligaments is shown in Figure 3.4 (White & Panjabi, 1990:21). According to this representation the curve can be divided into three regions: The neutral zone (NZ) – the displacement beyond the neutral position of the ligament due to a small force; the elastic zone (EZ) – the displacement beyond the neutral zone to the physical limit of the ligament and the plastic zone (PZ) – beyond the elastic zone and until failure occurs. The neutral and elastic zones combine to form the physiological range of motion. The viscoelastic properties of a ligament are another important characteristic, but there are limited research data available concerning such characteristics (Teo and Ng, 2001).

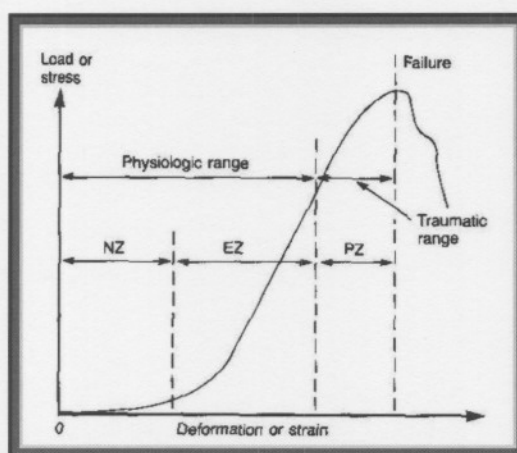


Figure 3.4: A typical load-deformation curve of a spinal ligament, obtained in a material testing machine (White & Panjabi, 1990:21)

Cryomicrotomy techniques have been used to quantify ligament geometry. It obtains sequential images in a predetermined plane at very close intervals, thus describing the three dimensional geometry. The specimen can be frozen in a predetermined state, for example, in a neutral spine position, thus preserving the in situ features of the spinal column. Because the body resists and reacts to various external loads in a dynamic environment, ligament tears have been documented during high rates of load. Avulsion of the ligament from the bone has been identified during slowly applied loads. These studies indicate the viscoelastic properties of the ligament structures.

Ligaments are deformation sensitive, i.e., once a stretch level is attained, regardless of the loading rate, the ligament will fail (Yoganandan *et al*, 2001).

3.2.2.4 Spinal Cord

A succinct discussion of the spinal cord anatomy and physiology follows (Snell, 2001:141). The junction of the medulla and the spinal cord lies at the level of the foramen magnum of the occiput. The spinal cord ends at or near the level of the first lumbar intervertebral disc. The relatively greater length of the spinal column compared to the spinal cord accounts for the difference in length and the descending obliquity of the ventral and dorsal nerve roots. Only in the cervical region do the spinal nerve roots maintain their nearly horizontal course that they followed until the third foetal month, when disproportionate growth begins.

There are eight pairs of cervical nerves. The first emerge through the atlanto-occipital membrane just superior to the posterior arch of the atlas. The eighth nerve emerges through the foramen between the seventh cervical vertebra and the first thoracic vertebra. Each of the remaining six emerges through an intervertebral foramen formed between cervical vertebrae.

An encroachment upon the spinal cord or other lesion that develops from the exterior inwards destroying representation of the distal parts of the body (e.g. lower limbs) first, and as the damage progresses centrally into the cord more superior parts of the body (e.g. the upper limbs) are successively affected. The reverse is also true. A lesion that begins centrally in the cord produces a sensory or motor loss of more proximal parts of the body first. There is segmental representation of the muscles supplied by the ventral root and the equivalent segmental representation of the sensory fibres that enter over the dorsal root. Therefore specific muscle paralysis and sensory loss can be of assistance in determining the level of the injury of the cervical spinal cord (Snell, 2001:143).

The blood supply to the spinal cord are the longitudinal arteries arranged as a single median anterior spinal artery and right and left posterolateral arteries. Longitudinal

strain more readily disrupts the plexus of capillaries in the grey substance than the white substance. With compressive loads there is not only horizontal strain at the level of the compression, but a longitudinal strain above and below the level. This explains why haematomyelia spreads superior and inferior beyond the local level of the compression.

Each cervical dorsal root ganglion is found just inside the intervertebral foramen. At the level of the ganglion the dorsal and ventral roots unite to form the spinal nerve, which emerges through the foramen with a sheath of dura mater. Each spinal nerve divides into anterior and posterior rami. The posterior rami pass backward at once to supply the intrinsic spinal musculature and the overlying skin. The anterior primary rami continue laterally and those from the fifth to the eighth form the brachial plexus, which supplies the muscles and skin of the upper quarter. Due to the direction of the nerves in the brachial plexus, downward traction on the arm or shoulder as well as excessive lateral bending of the neck to the opposite side are likely to stretch the nerves of the plexus. Disruption of these nerves will result in paresis of various muscles of the upper quarter and / or corresponding sensory loss. Minimal damage or strain in fibres of the fifth and sixth nerves may give transitory episodes of burning paresthesia and paresis in the upper limb (Snell, 2001:144).

3.2.2.5 Muscles

The muscles of the cervical spine will be discussed in more detail in the therapeutic exercise programme, but the following are the most important muscles of the cervical spine. The anterior muscles of the cervical spine are called the prevertebral muscles. Rectus capitis anterior, rectus capitis lateralis, longus capitis, longus colli and the eight pairs of hyoid muscles comprise these muscles. With bilateral tension of these muscles flexion of the cervical spine occurs and with unilateral contraction lateral flexion and rotation occur.

The splenius capitis and splenius cervicis are the primary cervical extensors. The suboccipital muscles comprise the rectus capitis posterior major and minor and obliquus capitis superior and inferior. With bilateral contraction extension of the

cervical spine is produced and with unilateral contraction lateral flexion and rotation occurs. The sternocleidomastoid, levator scapulae and the scalene anterior, posterior, and medius form part of the muscles on the lateral aspect of the neck. These muscles also produce flexion, extension, lateral flexion and rotation when acting either bilaterally or unilaterally (Hall, 1999:296-304).

3.2.2.6 The Zygapophyseal Joints

The zygapophyseal joints are present from the occiput to the sacrum and are classified as synovial joints (freely movable) that are multi-axial. The articular processes arise from the junction of the pedicles and the laminae of each vertebra. The articular surfaces of these joints are covered by articular cartilage and enclosed by a fibrous capsule that is reinforced posteriorly by the multifidi muscles. The joint capsule is particularly lax in the cervical spine to provide ample movement for the cervical spine. A synovial membrane lines the interior of the joint capsule and secretes a lubricant known as synovial fluid (Mercer and Bogduk, 2001). Theories in human joint mechanics suggest that the synovial fluid between articular cartilages maintain the fluid / solid interaction and therefore the cartilages do not come into contact with one another during normal load transmission (Kumaresan *et al*, 1998).

Like the intervertebral discs the zygapophyseal joints respond to multiple load vectors. The zygapophyseal joints play a complimentary role to the intervertebral discs. The load shared by the zygapophyseal joints changes with degeneration of the discs, joints and vertebral body. Because the zygapophyseal joints contain pain sensitive structures any deviation from their normal physiological function due to degenerative disorder or trauma may lead to facet induced pain in the head, neck or shoulders depending on the level affected (Yoganandan *et al*, 2001).

The zygapophyseal joints contribute to the stability of a motion segment. If the zygapophyseal joints are removed during surgery the segment is rendered unstable. Nachemson and Evans (1968) studied FSUs with and without the posterior elements and concluded that the zygapophyseal joints carry approximately 18 % of compressive load. King *et al* (1975) suggested that the load sharing mechanism of the

disc and zygapophyseal joints is a complex mechanism which depends on the dynamic movement of the spine and the posture of the spine. They concluded that the load carried by the zygapophyseal joints varied between zero and 33 %. The zygapophyseal joints could be unloaded when the capsular ligaments were under maximum strain.

Farfan (1973) found that under torsional strain 45 % of the load is shared between the disc and anterior longitudinal ligament and 45 % is shared by the zygapophyseal joints and capsular ligaments with the final 10 % shared by the interspinous ligaments.

Ahmed et al (1988) concluded that the zygapophyseal joints act as stops for axial rotation and this may prevent torsional injury to the disc. The torsional strain which the disc can sustain is more than the rotation allowed by the stop from the zygapophyseal joints. The zygapophyseal joints also prevent anterior shear. The zygapophyseal joints carry one third and the disc two thirds of anterior shear load when the load is suddenly applied. When the load is slowly applied the disc, because of its viscoelastic properties, will creep anteriorly and thus increase the load on the zygapophyseal joints. Lorentz et al (1983) found that the load on the zygapophyseal joints varies from 9 % in the neutral position of the spine to 15 % in extension. Yang and King (1984) found that the load can increase to 47 % in the arthritic zygapophyseal joint. The latter authors also proposed a new model for load transfer in a functional spinal unit (FSU). As the spine fully extends the tip of the inferior facet contacts the pars interarticularis of the vertebra below it. With further extension it results in the vertebra being pivoted around the facet tip and thus the capsular ligaments are stretched.

The aim of the detailed discussion on biomechanics and description of the cervical spine above was to prepare for the discussion on how the cervical spine could be injured and to develop a better understanding of biomechanical dysfunction of the cervical spine that could influence the cervical spine of a schoolboy rugby player. Understanding the complexity of the cervical spine and surrounding soft tissues is also essential in the development of an evaluation technique as well as a technique for the correction of cervical biomechanical dysfunction.

3.3 Summary

This chapter considered the anatomy and biomechanics in general and then focused on the anatomy and biomechanics of the cervical spine. The following chapter of the literature review will focus on human movement, and in particular motion segment analysis of the cervical spine, since this concept will be used in the radiological and physiotherapeutic assessment of the cervical spines of the schoolboy rugby players.

Chapter 4

Literature Review on Human movement

The following section will discuss the technical terminology used to describe human movement. These terms will then be used to discuss the movement of a motion segment of the cervical spine in more detail.

4.1 Introduction to human movement

For any human being it is essential to move. Muscle contraction is essential for movement which is necessary for respiration and blood circulation. In mechanical terms movement take place in two ways: linear motion, in which a body moves either in a straight or curved line, and angular or rotational movement in which a body rotates around a fixed line. Human movement normally can be described as both linear and rotational, for example walking. The femur has a linear motion in a forward direction while rotating around an axis of the hip joint. Movement can also be described in various ways. One perspective internal mechanics, considers the factors within the body that produce and control movement, and another perspective, external mechanics, considers external forces that influence movement.

In this study the internal forces acting on the cervical zygapophyseal joints, such as the muscles and ligaments around the joints are considered in the development of biomechanical dysfunction of the cervical spine. The external forces, such as the forces transmitted through the cervical spine during a scrum or a tackle, are also considered as possible causal factors for biomechanical dysfunction in the cervical spines of rugby players.

4.2 Terminology used in the Description of Human Movement

4.2.1 Unit vectors

A unit vector is a vector the length of which equals 1. It is used to define a direction in space. In the lower cervical spine the facet plane is tilted approximately 45 degrees to the frontal plane and 90 degrees to the sagittal plane. This could be put together to form a unit vector N , which is perpendicular to the plane of the facet (Panjabi & White, 2001:8). See Figure 4.1.

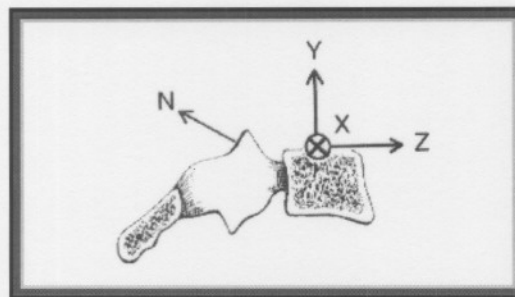


Figure 4.1: Unit vector. Orientation of the facet plane of the lower cervical vertebra is advantageously defined with the help of the concept of the unit vector (Panjabi & White, 2001:8)

4.2.2 Degrees of Freedom

This is the number of independent coordinates in a coordinate system that are required to completely specify the position of the object in space. This can also explain the independent planes of motion in which an object can move. A rigid body has six degrees of freedom: 3 translations and 3 rotations. A vertebra has 6 degrees of freedom. It can translate along any 3 axes and can rotate around any of the 3 axes. Motion does not necessarily occur around or along a pure axis and therefore motion can be broken down into its components and shown to be composed of various

combinations of translations and rotations about these axes (Panjabi & White, 2001:8–20).

4.2.3 Axis of Rotation

When a rigid body moves in a plane there is a point, or some hypothetical extension of it that does not move. This is the axis of rotation of the body for that step of motion. Because joints in the human body are not perfect hinge joints, the location of the axis of rotation relative to the bony structures at any instant in time changes as well. These changes in muscle force, line of action and moment arm results in a continuously varying moment in force. The asymmetry of joint motion is caused by three factors: rotation, sliding and rolling. When a vertebra moves from flexion to extension it has a set of axes of rotation in relation to the outside frame of reference (global movement) as well as reference to each of the other vertebrae (relative motion). As a vertebra moves from flexion to extension various components such as muscles and ligaments come into play and can influence the axis of rotation.

4.2.4 Coordinate System to describe Motion

A rectangular coordinate system best describes the neuromusculoskeletal system. This coordinate system is also known as the right-handed Cartesian coordinate system. This system could be defined as three straight lines mutually perpendicular and intersecting one another. The lines are referred to as the x, y and z axes and their point of intersection are called the origins. A Cartesian coordinate system with its origin between the coruna of the sacrum has been suggested for the human body. The planes of motion are the sagittal or yz – plane, frontal or coronal or xy – plane, and the transverse or horizontal or zx – plane. Motion can be described in terms of translation (T) and / or rotation (R) along or around the three axes. Thus translation to the left is +Tx, up is +Ty and forward is +Tz. Similarly translation to the right is –Tx, down is –Ty and backwards is –Tz. For clockwise rotation, rotation will be to the right. Therefore +Rx is flexion around the x axis in the coronal plane, +Rz could be described as right lateral bending around the z axis in the frontal plane and +Ry is rotation to the left around the y axis in the sagittal plane. In spinal kinematics the

motion is usually described in relation to the subjacent vertebra so that the local coordinate system is established in the body of the subjacent vertebra (Panjabi & White, 2001:4–7). See Figure 4.2.

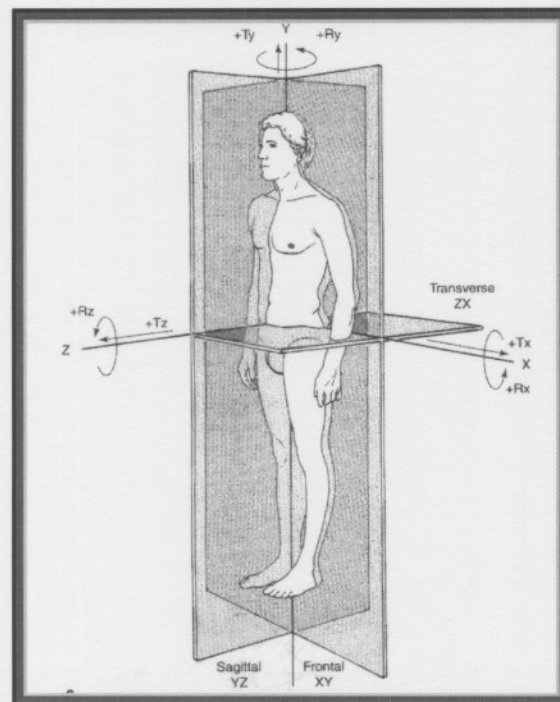


Figure 4.2: Right-handed Cartesian: x , y , z . Translations (T_x , T_y , T_z) along the direction of the arrows and clockwise rotations (R_x , R_y , R_z) around the arrows are considered as positive motions. The opposite motions are negative (Panjabi & White, 2001:6).

The following section will describe movement of the cervical spine in terms of motion segments, since one of the primary physiotherapeutic aims of the study is to validate a manual physiotherapy evaluation technique for motion segment analysis.

4.3 Segmental Motion of the Cervical Spine

Early studies of the cervical spine examined the range of motion of the entire neck, typically by applying a goniometer to the head. Although these studies provide

implicit data on the global function of the neck, they do not reveal what is actually happening inside the neck (Bogduk & Mercer, 2000).

It is worthwhile to study the regional characteristics and spatial orientation of the vertebrae in different regions of the spine in relation to the biomechanics of the spine. When considering the motion segments of the spine one generally assumes that the intervertebral disc space is horizontal and parallel to the bottom of this page. In fact only a few motion segments are parallel to the horizontal plane. In the normal individual this occurs in the region of C3 – C4, the mid-thoracic region and L3 – L4 in the lumbar spine (White & Panjabi, 1990:48).

According to Kapandji (2002), as well as Bogduk and Mercer (2000), the cervical spine could be divided into two anatomically and functionally distinct segments, namely the superior or suboccipital segment, containing the atlas and the axis, and the inferior segment, stretching from the inferior surface of the axis to the superior surface of the first thoracic vertebra. For the purpose of this study the inferior or lower cervical spine was investigated, since most of the pathology found in the cervical spines of schoolboy and adult rugby players were in the lower cervical spine.

4.3.1 Motion Segment

The Motion segment or functional spinal unit (FSU) is the smallest segment in the spine that exhibits biomechanical characteristics similar to those of the entire spine. It consists of two adjacent vertebrae and their connecting soft tissue structures. For studies the lower vertebra is fixed and the loads are applied to the upper vertebra and its response is measured. The behaviour of a motion segment is dependent upon the physical properties of the components and their articular surfaces. The entire spine is composed of multiple motion segments connected in series and the spine's total behaviour may be approximated as a composite of the behaviours of the individual motion segments (White & Panjabi, 1990:46-49).

4.3.2 Flexibility and Neutral Zone

Flexibility is the ability of the structure to deform under load and stiffness is the opposite. Experiments have shown that motion segments are more flexible in tension than in compression in all directions. In the cervical spine the tensile flexibility is approximately four times that of the compressive flexibility. The shear stiffness is about 25 % in the cervical spine when compared with the axial compressive stiffness.

The neutral zone for flexion / extension of the lower cervical spine is the largest of the entire spine and the smallest zone is between C0 and C1. For lateral bending, the neutral zone is also the largest in the lower cervical spine and the smallest between C1 and C2. For axial rotation the largest neutral zone is found between C1 and C2 (Bogduk & Mercer, 2000).

4.3.3 Three Dimensional Motion

A typical motion segment of the spine can move along or around all three axes (sagittal, frontal and transverse) and this could be called a three dimensional motion. Twisting of the spine is a good example of three dimensional motion. This is possible because of the structure of the motion segment and the articulation between the vertebrae that form the motion segment. A motion segment that moves in three dimensions is called coupled motion. With flexion of the spine the vertebra rotates and translates forward and downward. Rotation can be described as the main motion and the translation as the coupled motion (Panjabi & White, 2001: 21–25).

4.3.4 Zygapophyseal joints of the cervical spine in Motion Segment Analysis

The motions of the cervical spine are strongly influenced by the zygapophyseal joints. Pure lateral flexion and rotation of the cervical motion segments are known to be limited, for example, by an intact vertebral ring and facet joints (Onan *et al*, 1998).

The cervical intervertebral joints are saddle joints which consist of two concavities facing one another and set at right angles to one another, therefore shaped like the seat of a riding saddle. The pattern of movement of the spine, is amongst other factors, dependent on the shape and position of the articular processes of the synovial joints. It is their orientation in space that determines their mechanical importance. Across the sagittal plane the inferior surface of the vertebral body is concave downwards, while across the plane of the zygapophyseal joints the unciniate region of the lower vertebral body is free to rock forward in the sagittal plane around a transverse axis, and is free to rock side-to-side in the plane of the facets, around an axis perpendicular to the facets. Motion in the third plane, that is, side-to-side around an oblique anterior – posterior axis is precluded by the orientation of the facets. This description appears dissonant with traditional ideas that typical cervical segments exhibit flexion / extension, lateral flexion and axial rotation. However it allows for flexion and extension, but stipulates that the only pure movement is rotation around an axis perpendicular to the facets. Since the facets are oriented at about 45° to the transverse plane, the axis of rotation is 45° from the conventional axes of both the horizontal axial rotation and lateral flexion (Bogduk & Mercer, 2000). See Figure 4.3.

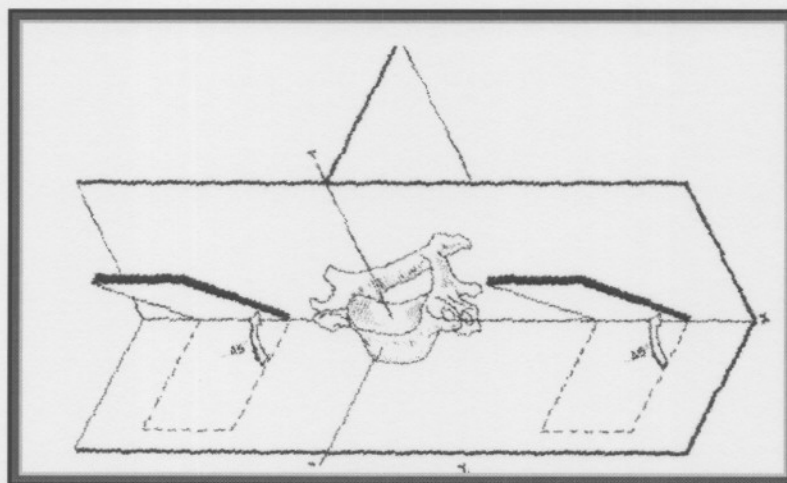


Figure 4.3: Orientation of the cervical facet joints represented graphically at approximately 45° to the x-axis (White & Panjabi, 1990:30).

The torsional stiffness of the spine largely depends on the design of the zygapophyseal joints. According to Panjabi (1998), the zygapophyseal joints of the

cervical spine and the joints of Luschka are the major contributors to coupled motion in the lower cervical spine and the uncinat processes effectively reduce motion coupling and primary cervical motion (motion in the same direction as load application), especially in response to axial rotation and lateral bending loads.

Onan et al (1998) stated that the cervical zygapophyseal joints have a coronal orientation consistent with a weight-bearing function. Zdeblick et al (1993) suggested that the zygapophyseal joints contribute significantly to the stability and the stiffness of the cervical spine. In their study they were primarily concerned with the mechanical behaviour of zygapophyseal joints of the cervical spine in isolation. The study was conducted on five freshly harvested human cervical spines with an average age of 66. They found that maximum anterior translations of the anterior edge of the upper facet relative to the lower facet remained less than 3 millimetres for the intact motion segment. After the posterior longitudinal ligament, disc and anterior longitudinal ligament were removed and the interspinous ligament cut, the anterior translations increased to between five and six millimetres when the zygapophyseal joints were tested in isolation. Flexion loads usually lead to these maximum values. The laxity of the facet capsules implies that large motions would have to occur to stretch the joint capsule. This large degree of laxity is most likely to be needed for flexion and rotation of the cervical spine. The results of their study also showed that lateral bending and rotational stability was maintained even after removal of the anterior and posterior longitudinal ligaments and disc and cutting off the interspinous ligament. A vertebral ring with intact zygapophyseal joints and capsule seems essential for lateral bending and axial rotation stability of the cervical spine.

The flexion and extension movements of the cervical spine will be explained in the following section since the x-rays which will be taken of the schoolboy rugby players for the empirical study will be of the cervical spine in flexion and extension. Rotation and lateral bending combined movement will also be discussed since these movements are used in the manual physiotherapy evaluation and treatment techniques. The author mainly used by the researcher for these sections is Kapandji (2002) since he has been acknowledged as a leader in this field for many years.

4.3.5 Flexion and Extension of the Cervical Spine

In the neutral position, the vertebral bodies are connected by the intervertebral disc. In this position of equilibrium the fibres of the annulus fibrosus are uniformly stretched. The vertebral bodies are also connected by their articular processes (the zygapophyseal joints), the surfaces of which are oblique inclined inferiorly and posteriorly. In this part of the spinal column the joint surfaces of the articular processes are saddle shaped (Chapter 4:73).

During extension the overlying vertebral body tilts and slides posteriorly. The intervertebral space is compressed posteriorly, the nucleus pulposus is driven slightly anteriorly and the anterior fibres of the annulus fibrosus are stretched. The interspace of the joints between the articular processes is widened anteriorly. Extension is limited by tension developing in the anterior longitudinal ligament and by the impact of the superior articular process of the lower vertebra on the transverse process of the upper vertebra.

During flexion the upper vertebra tilts and slides anteriorly and this results in compression of the intervertebral space anteriorly. This drives the nucleus pulposus posteriorly and stretches the posterior fibres of the annulus fibrosus. The inferior facet of the upper vertebra moves superiorly and anteriorly and the interspace is opened up posteriorly. Flexion is not limited by any bony impact, but by tension developing in the posterior longitudinal ligament, the capsular ligament, the ligamenta flava, the ligamentum nuchae and the posterior cervical ligament (Kapandji, 2002:196).

In the cervical spine motion between adjacent vertebrae is also influenced by two additional joints, the uncovertebral joints (joints of Luschka). In a frontal section of a cervical motion segment the disc does not reach the lateral margins of the vertebrae. The superior plateau is raised laterally by two buttresses lying in the sagittal plane. The cartilage lined articular surfaces of these unciform processes face medially and superiorly and corresponds to the cartilage lined semilunar facets of the inferior plateau of the upper vertebra, the latter facets face laterally and inferiorly. These small

joints are enclosed within a capsule which continuous medially with the intervertebral disc (Kapandji, 2002:196).

The unciform processes “guide” the vertebral body into the anteroposterior movement of flexion and extension. During lateral bending the interspaces of the unco-vertebral joints open out and stretching of the capsule of the contralateral uncovertebral joint occurs. The nucleus pulposus of the intervertebral disc is displaced to the contralateral side. Lateral bending in the cervical spine does not occur in isolation, but is accompanied by rotation, therefore movements of the uncovertebral joints in reality are far more complex (Kapandji, 2002:198).

4.3.6 Combined Rotation and Lateral Bending

Current theory is that the oblique orientation of the facet joints and their orientation to one another is the explanation for the complex coupled rotations demonstrated in the cervical spine (Onan *et al*, 1998). Complex motion of the cervical spine is essential for normal function and even more so in the cervical spines of schoolboy rugby players.

Considering the orientation of the facet joints the following sliding motions are possible. In the event of combined equal sliding of both surfaces, both facets slide superiorly during flexion and inferiorly during extension. When the facets slide differentially or relative to one another, the following occurs: With the left facet sliding superiorly and anteriorly, the right facet will slide inferiorly and posteriorly. The movement produced is a combination of rotation and lateral bending (Kapandji, 2002:200).

Horizontal rotation is inexorably coupled with lateral flexion, and vice-versa. If horizontal flexion is attempted, the inferior articular process must ride up the slope. As a result, the vertebra must tilt to the side of the rotation. A reciprocal combination of events results when lateral flexion is attempted. Downward movement of the ipsilateral inferior articular process is arrested by the upward facing superior articular process, but is permitted if the inferior process slides backwards down the slope of the

superior process. As a result the vertebra must rotate to the side of lateral flexion (Kapandji, 2002:200).

In a study by Bernhardt et al (1999) an attempt was made to recreate *in vivo* loading conditions with *in vitro* spine testing by developing a pneumatic loading system capable of simulating eight muscle forces simultaneously. One of their objectives was to determine the intersegmental and coupled motions using an ultrasonic tracking system and then to compare this with known *in vivo* studies. The results from this study correlated well with different mathematical models. For the purpose of this study, the intersegmental motion measured in the experiment by Bernhardt et al (1999) could not be used, since they used pure rotation and lateral flexion of each segment, and other biomechanical studies indicated that rotation is always coupled with lateral flexion to the same side.

4.3.7 X-ray Measurements of Segmental Motion

Segmental motion is analysed from lateral flexion and extension views of the cervical spine. The pioneering work by Penning (1978) stated that segmental motion is not simply a rocking about a pivot located in the centre of the disc, but a complex motion composed of rotation and posteroanterior translation of the vertebrae relative to each other. The early studies measuring cervical spinal segmental motion were marred by lack of attention to the reliability of the technique used and inter-observer and intra-observer errors were not reported. The studies conducted in recent years that stated inter-observer and intra-observer reliability are few. One of the first of these studies was performed by Dvorak et al (1991) who measured *in vivo* flexion and extension of the cervical spine using x-ray measurements. It was decided to use the basic principles for manually marking the x-rays as described by these authors in identifying the landmarks used to perform the various x-ray measurements used in this study. This is described in detail in the Chapter 6 (Chapter 6:178).

Unfortunately the software used by these authors to digitise the x-ray images and assist in algorithmically determining the landmarks of the cervical vertebrae to be measured was not available to the researcher. Therefore the manual method used in

this study should not be considered as a gold standard for these x-ray measurements in schoolboy rugby players. However the same manual method for identifying landmarks on the x-rays was used for all x-rays and the same software program will be applied in all the x-ray measurements (Chapter 6:179). Accordingly one can conclude that any change in measurement outcomes can be considered indicative of a trend, but the reliability of this method should not be compared to the computer assisted results found by Dvorak et al (1991) due to potential manual variance in plotting the landmarks. Once landmarks are plotted for each cervical vertebra that will be measured the following measurement could be performed using the flexion / extension x-ray views.

- Flexion and extension angles.
- Angles of rotation.
- Anterior translation.
- Translation / rotation ratios.
- Axis of rotation and centres of reaction:

Frobin et al (2002) studied a total number of 137 sets of lateral x-rays with flexion and extension views and performed various measurements utilising these x-ray views. The subjects had a mean age of 33 for both genders and a radiologist examined the x-rays and found no pathology. They stated that the precise measurement of angles of rotation offers a precise tool to investigate and document effects of conservative or operative treatment. Frobin et al (2002) also described segmental motion in the cervical spine by a combination of rotation and posteroanterior translation. The latter was measured in the plane of the disc and quoted in relative units. A protocol for documenting segmental motion from lateral radiographic views in flexion and extension was developed with special emphasis on minimising measurement errors and on excluding subjective influence. Normal data for angles of rotation and translational motion were presented, and this could serve for documenting segmental motion abnormalities in future studies.

Table 4.1: Normative values for mean angles of rotation (Frobin *et al*, 2002).

Level	n	Range (°) males
C3/C4	92	11.6 (3.57)
C4/C5	95	14.4 (4.55)
C5/C6	92	12.2 (5.19)
C6/C7	23	9.8 (5.73)

It was decided to use the measurement protocols for measuring the flexion and extension angles, angles of rotation, as well as anterior translation; and normative data as described by Frobin *et al* (2002) for this study for the schoolboy rugby players. Their protocol is based on landmarks algorithmically identified on the skull and objective landmarks on vertebrae C1 – C7. The parameters describing rotational and translational motion are derived from these landmarks in such a fashion that the results are virtually uninfluenced by radiographic distortion and magnification. Special control of patient alignment is not required; normal positioning suffices. Frobin *et al* (2002) refer to previous studies performed on the lumbar spine ascertaining that in the lumbar vertebrae relative to the location of the midpoints between the anterior and posterior vertebral corners, location of the centre points, mean depth as well as location and orientation of the midplanes and their bisectors are virtually independent of the distortion in central projection and of small alignment errors of the patients. The definition of landmarks used in their study of the cervical spine was similar therefore their results could also be considered as being uninfluenced by distortion and patient alignment errors. These results were assumed by the researcher to be scientifically valid.

The definition of flexion and extension angles, angles of rotation and translational motion for the motion segments C3/C4 to C6/C7 are outlined as follows according to Frobin *et al* (2002) (see Figure 4.4):

- Corners 1 – 4 are located on the outer contours of the vertebral bodies by a computerised algorithm.
- The centre point of the vertebra is the geometrical centre of corners 1 – 4.

- The vertebral midplane is defined as a line running through the midpoint between corners one and three and corners two and four respectively.

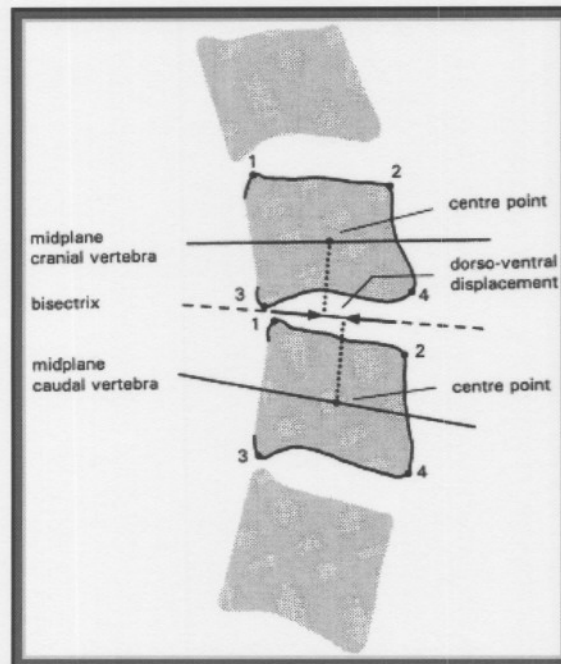


Figure 4.4: Method for measuring extension angle for a motion segment in the cervical spine region (Frobin *et al*, 2002).

The computer software used by Frobin *et al* (2002) to identify landmarks on the x-rays was not available to the researcher therefore it was decided to use the manual method of identifying the corners of the vertebrae as proposed by Dvorak *et al* (1991).

4.3.7.1 Flexion and Extension Angles between vertebrae

The angle between two vertebrae of a motion segment is given by the angle between their midplanes. The midplanes are constructed by determining the midpoint between corners 1 and 3 and 2 and 4 respectively (Figure 4.4). The angle is counted positive if the wedge opens anteriorly. The example illustrated in Figure 4.4 therefore represents the extension angle for this particular motion segment (Frobin *et al*, 2002).

4.3.7.2 Angles of Rotation

According to Frobin et al (2002) the angle of rotation for a motion segment could be defined as the difference of the angle in extension minus the angle in flexion and is quoted in degrees. This angle of rotation could provide an indication of the range of motion for a specific motion segment. A decreased angle of rotation will imply a hypomobile motion segment and an increased angle of rotation suggest a hypermobile motion segment (Frobin *et al*, 2002). It was therefore decided to calculate the angles of rotation for the various motion segments of the cervical spine for this study.

4.3.7.3 Translation

Perpendiculars are constructed from the centre points of adjacent vertebrae onto the bisectrix between the midplanes (Figure 4.4). Posteroanterior displacement is defined as the distance between those points where the perpendiculars intersect the bisectrix. Thus, displacement (and consequently translational motion) is measured along a direction coinciding in good approximation with the midplane of the disc. Frobin et al (2002) suggested that to correct for radiographic magnification and variations in stature, displacement measured in millimetres is divided by the mean depth of the caudal vertebra. The mean depth is the mean of the distance of corners 1, 2 and 3, 4, respectively. Translation motions are given in dimensionless quantities since the size of the vertebrae and the possible x-ray enlargement made it impossible to compare metric unit measurements. The software program which will be used by the researcher for the measurement of translation in this study also measures distance in standard units and not in metric unit measurements (Chapter 6:180).

Frobin et al (2002) ascertained that in lumbar vertebrae relative location of midpoints between the anterior and posterior vertebral corners, location of centre points, mean depth as well as location and orientation of midplanes and their bisectrix are virtually independent of distortion in central projection and of small alignment errors of the patients. As the definition of landmarks and derived parameters is similar for cervical and lumbar vertebrae, rotational and translational motion, as defined in the article by

Frobin et al (2002), are virtually uninfluenced by distortion and patient alignment errors.

4.3.7.4 Axis of Rotation

To be comprehensive measuring the axis of rotation will be discussed briefly although the researcher did not have the necessary software available to measure the axes of rotation for the various motion segments in the current study. The appertaining centres of rotation could be located by superimposing for the vertebrae images in flexion and extension. Penning (1978) found the centres of rotation to be located generally below the endplate of the caudal vertebrae.

When a cervical vertebra moves from full extension to full flexion its path appears to lie along an arc the centre of which lies somewhere below the moving vertebra. This centre is called the instantaneous centre of rotation (ICR) and its location can be determined using simple geometry. If tracings are obtained of lateral radiographs of the cervical spine in flexion and in extension, the pattern of motion of a given vertebra can be revealed by superimposing the tracings of the vertebra below. This reveals the extension position and the flexion position of the moving vertebra in relation to the one below (Bogduk & Mercer, 2000). The location of the ICR is determined by drawing the perpendicular bisectors of intervals connecting like points on the two positions of the moving vertebra. The point of intersection of the perpendicular bisectors marks the location of the ICR.

4.4 Manual Physiotherapy Evaluation of Segmental Motion

Abbot (2004) refer to studies done on the reliability of clinical examination in manual therapy, however the author stated that considerably less attention has been focused on validity. Validity in this context can be defined as the extent to which the test or measure actually measures what it intends to measure. With regard to manual therapy a query may be made as to whether the parameters of motion which are intended to be

perceived manually, actually represent meaningful parameters of motion important to movement dysfunction, e.g. neck pain.

The ability to palpate a spinous process is considered a basic skill and a prerequisite for manual therapy techniques (Jull *et al*, 2002; Petty & Moore, 1998 and Billis *et al*, 2003). If therapists are unable to reproduce the same spinous process by palpation, it is not unreasonable that other spinal manual therapy techniques (based on palpation) would lack reproducibility, too. In addition, other spinal structures which are believed to be more difficult to palpate (e.g. transverse processes), are likely not to be palpated consistently. The lack of agreement among physiotherapists highlights the need for investigation of methods of palpation in order to establish which levels are the most reproducible (Billis *et al*, 2003). They concluded that physiotherapists have fairly poor reproducibility and good repeatability in locating C5, T6 and L5 spinous processes by palpation.

Manual therapists also routinely assess spinal segmental movement, and choose interventions on the basis of the findings of those assessments. Movement abnormalities such as hypo- or hypermobility, are believed to be detected by these assessments. Despite their widespread use, the validity of clinical examination items for detecting cervical spine intersegmental movement has received very little attention. Inter-examiner reproducibility of physical examination of the cervical spine was investigated by Pool *et al* (2004). They studied two physiotherapists who independently judged the general mobility and intersegmental mobility (C0 – T2) of the neck, and the pain that was provoked. Percentage agreement and Cohen's kappa expressed agreement of dichotomous variables, limits of agreement expressed agreement of continuous variables and inter-class correlation coefficient expressed the reliability of continuous variables. Despite the use of standardised protocol to assess general mobility and intersegmental mobility of the cervical spine it is difficult to achieve reasonable agreement and reliability between two examiners. Likewise the patients were not able to score the same level of provoked pain in two assessments with an interval of 15 minutes. It was therefore decided to test the validity of a specific manual therapy motion segment assessment technique for validity against an objective measure, in this case x-ray analysis.

According to Feipel et al (1999) the best method to evaluate segmental motion analysis is with radiography. They state that no validated cost effective external measurement for segmental motion analysis is available. They do not mention any manual therapy techniques in their investigation. One of the aims of the current study was to investigate the use of a manual therapy evaluation technique in motion segmental motion analysis, comparing this technique with the results from the segmental motion segment analysis from radiography.

Hypomobility of one vertebral motion segment upon another has been described and accepted by a broad spectrum of clinicians. Gillet (1968) described early movement palpation techniques to assess hypomobility techniques. Breig (1960) concluded that angulation between vertebrae was due to pathological biomechanics of the cervical spine, causing a lever action during flexion, with resultant distortion of the root sleeves and accompanying degenerative changes of the intervertebral disc. Gillet (1968) quoted Jackson's theory that when this occurred in the cervical spine it would result in a compensatory mechanism attempting to make up for the loss in movement. The latter noted that in flexion of the cervical spine an angle was created at the C5 / C6 intervertebral space, which with time spread, progressively higher as degenerative changes occurred at each compensating intervertebral level.

As stated in chapter 1 normal biomechanics of a motion segment could be described as the position where the motion segment is held in a physiological state of rest (Chapter 1:4). This would imply the least amount of intra-joint pressure, least amount of connective tissue tension and the least amount of electromyographic (EMG) muscle activity. Considering this, dysfunction of a motion segment could therefore be described as any position where the motion segment is not in a physiological state of rest. With dysfunction normal movement of the segment will be affected with restriction to one or more directions of the movement.

According to Rocabado (1999) the motion segment movement pattern of cervical rotation with lateral flexion to the opposite side is an indication of the flexion movement potential of the motion segment. He stated that in the event of restriction of this movement pattern one can expect restriction of the flexion movement for that particular motion segment. If restriction of the movement of rotation and lateral

flexion to the same side is found, this would indicate restriction of extension movement for that specific motion segment. This evaluation technique has to date not been validated through research and therefore one of the primary physiotherapeutic aims of the study will be to test the validity of this evaluation technique as described by Rocabado (1999). This manual physiotherapy technique will be described in detail in the following chapter.

4.5 Manual Physiotherapy Treatment for the Correction of Cervical Spine Biomechanical Dysfunction

Studies investigating the efficacy of physiotherapy in the treatment of neck pain have been disappointing. Reviewing the literature of treatment modalities used by these investigators, manual therapy were not included as part of the treatment protocol in any of the found studies and further no mention was made of correcting biomechanical dysfunction. Systematic reviews published in 1996 and 1997 concluded that there is little information available from clinical trials to support many of the treatments for mechanical neck pain and that conservative interventions have not been studied in enough detail to assess the efficacy adequately (Alaranta *et al*, 1994; Holmström *et al*, 1992; Winer, 1971).

The number of randomised control trials in the field of neuromusculoskeletal therapy is increasing, yet there is still a comparatively small quantity of evidence available to support many aspects of practice and policy (Moore & Jull, 2003). For this study the treatment technique as taught by Rocabado (1999) in his Module 2 course was performed. The technique will be detailed in the following chapter (Chapter 6:180).

In a biomechanical model of neuromusculoskeletal pain it is assumed that pain and pain recurrence are due to repeated mechanical irritation of pain sensitive structures (Panjabi, 1992), and it is proposed that improved control and stability would reduce mechanical irritation and lead to pain relief. This model has acceptable validity. In terms of the muscles of the spine, both the properties of the muscle (strength and

endurance) and the properties of the system which controls the activity of the muscles are important. The neuromuscular control system detects the status of stability, and plans muscle activity, in advance of, or in response to, perturbations to the spine (Panjabi, 1992). According to this model, any alteration in the recruitment strategy for spinal control may lead to microtrauma and subsequent nociceptor stimulation and pain. It is argued that motor control should be the focus of the intervention. The other elements of a rehabilitation programme should however not be excluded.

Information is limited regarding which rehabilitative conservative management or therapy combination is most effective in treating acute or chronic cervical pain (Gross *et al*, 1996), and studies regarding the correction of cervical biomechanical dysfunction in schoolboy rugby players could not be found in the literature. One of the primary physiotherapeutic aims of the study therefore is to determine the effectiveness of this manual physiotherapy treatment technique for the correction of cervical biomechanical dysfunction in schoolboy rugby players.

4.6 Development of a Therapeutic Exercise Programme for the Correction of Cervical Biomechanical Dysfunction.

Physiotherapists have used exercises for the management of neuromusculoskeletal conditions since the profession emerged (Hodges, 2004). Although the general goal of exercises in the management of neuromusculoskeletal conditions has generally aimed at improving movement performance, the strategies used and the specific goals have evolved over time. For example, early intervention for lower back pain focussed on improving the strength and endurance of the trunk muscles, with the basic goal to improve the strength and stability of the spine. More recently exercise interventions have evolved to focus on issues of motor control, rather than primary emphasis on muscle parameters, however the goal remains essentially the same.

The aim of the therapeutic exercise programme developed by the researcher for the current study is to correct cervical biomechanical dysfunction of the schoolboy rugby

player. The therapeutic exercise programme was based on the manual therapy treatment technique, but adapted in such a way that this programme could be implemented for schoolboy rugby players by any skilled coach and / or educator. This could be explained as a team approach instead of the individual approach by the manual physiotherapy treatment technique. The therapeutic exercise programme for the correction of biomechanical dysfunction will be detailed in the Chapter 6.

4.7 Degenerative Changes of the Cervical Spine

As with all synovial joints the zygapophyseal joints can also be deformed and damaged when overloaded. In order to minimise the forces acting on the spine the load is spread evenly throughout the spine and the activity of the paraspinal muscles also decrease the forces of the loads. Sustained postures and sustained excessive compression forces causing loss of height of the intervertebral discs, if continued over time, eventually may lead to subluxation of the zygapophyseal joints (Mitchell, 1994). This is of importance in considering the current study since the studies by Scher (1990) and O'Brien (1996) indicated signs of early degenerative changes in the cervical spines of rugby players. An aim of this study was to restore normal biomechanics of the cervical spine with the view that this would in the long-term reduce the early degenerative changes found and discussed in the literature.

Scher (1990) suggested that rugby players are prone to early degenerative changes of the cervical spine. He performed lateral radiographs of the cervical spines of 150 rugby players, still actively involved in participation in club rugby. Three groups of 50 players aged 20 – 25 years, 25 – 30 years and 30 – 35 years were selected. Each group included 25 forwards and 25 backs. All the subjects included were volunteers and participated in the investigation with the co-operation of the secretaries of senior rugby clubs in Cape Town, South Africa. All the subjects were asymptomatic at the time of the investigation. A control group of 150 men who did not play rugby was selected from patients referred to the Department of Radiology from the General Outpatients Department of the Tygerberg hospital, Cape Town. Similar criteria for selection were followed in order to provide an identical sample with regard to age. These volunteer subjects had no symptoms or signs of arm or neck pain at the time of

the examination. The study revealed that 40 players had degenerative changes and that eight of the players had previous fractures. In the control group only one subject had a previous fracture. In the general population it is only at 40 to 50 years of age that 25 % to 29 % showed degenerative changes.

This work has been repeated by Berge et al (1999) with magnetic resonance imaging (MRI) scanning. They compared 47 front row players to 47 controls and found more degenerative changes in the rugby players. They also found that the diameter of the spinal canal was decreased in all the players. Silver (2002) concludes that rugby causes degenerative disease of the spine which will result in long term morbidity to the player.

The following section will explain the theory the researcher used in the development of the therapeutic exercise programme used for the rehabilitation of the neck of schoolboy rugby players. The section will start with the basic knowledge in motor learning since these concepts are essential for any person teaching a new movement pattern to a schoolboy rugby player. This will be followed by motivation for each exercise designed for the programme.

4.8 Development of a Neck Rehabilitation Programme

To develop a neck rehabilitation programme for a schoolboy rugby player the basis of each exercise must be research founded and the effect of the exercise in terms of neuroscience well understood. The player needs to be addressed in terms of the biopsychosocial model.

This section will therefore begin with an introduction, followed by an overview of the neuroscience of motor learning and motor control. This will be followed by evidence based motivation for each component of the neuromusculoskeletal based therapeutic exercise programme for the rehabilitation of the cervical spine. Motivation for the visual presentation as well as general principles of the neck rehabilitation programme will also be discussed in detail, based on evidence found in the literature.

4.8.1 Introduction

When prescribing a rehabilitation programme for a rugby player a holistic programme must be considered (Trew & Everett, 2001:119). For the purpose of this study however, a therapeutic exercise programme for cervical spine rehabilitation was developed as an intervention for possible biomechanical dysfunction and therefore the cervical spine was the focus of this study. The rugby players who participated in this study continued with their normal programme, which could be considered a holistic programme. The ideal would be to develop an individual programme for each player that could be constantly changed and adapted to individual needs. This was however not possible in the present study since one of the aims of the study was to develop an exercise programme that could be implemented for all schoolboy rugby players with a positive outcome. This therapeutic exercise programme could be introduced to schoolboy rugby coaches and other healthcare professionals.

Following a randomised controlled trial (RCT) Jull (2004) suggested a neck rehabilitation programme for patients suffering from acute whiplash. It was proposed that physiotherapy management should include a specific multi-modal rehabilitation programme, based on a programme with proven efficacy for cervical disorders. This should include assurance, education and ergonomic advice, a graded specific therapeutic exercise programme emphasising restoration of active stabilisation, manual therapy and electrotherapy modalities as indicated. Revel et al (1994) suggested that if subjects presented with deficits in postural control, a programme retraining cervico-cephalic sensibility and balance should be included in a rehabilitation programme. Even though the schoolboy rugby players of the current study could not be considered as having acute neck injuries, these basic elements for rehabilitation of the cervical spine were included in the design of their programme.

Scher (1991) suggested that the cervical spine muscles should be voluntarily tensed during the moment of impact to decrease the impact on the cervical spine. This could be used during the scrum and when performing a tackle on an opponent, but in some instances a player is unexpectedly tackled by an opponent.

Noble (1988) suggested that neck conditioning programmes should start at junior level and be well supervised. Several studies (Maroon, 1981 and McCoy *et al*, 1984) found that most teams do not have a definite programme for neck strengthening and that only isometric exercises were included by those who pay attention to neck strengthening. Watson (1981) found that flexibility and upper back strength were the most noticeable deficiency in schoolboy rugby players, but that methods for strengthening neck and upper back muscles received little attention.

According to Mosely (2004) variability is essential for learning. Therefore a number of exercises were included in the therapeutic exercise rehabilitation programme with the intention that the schoolboy rugby players would not become bored. The exercises were also progressed in such a way that there was always a challenge for the subjects.

It is important to note that the subjects participating in the current study were pain free with no previous neck injury. In the event of pain or injury for a player who did not participating in the study, the player was advised to undergo thorough investigation and be treated accordingly. Following treatment a rehabilitation programme should then be implemented, following the different stages of rehabilitation, acute, sub-acute and final rehabilitation. Stage 1 and 2 rehabilitation should be performed by a skilled physiotherapist.

A neuromusculoskeletal theoretic approach was used in the development of this therapeutic exercise programme for cervical spine rehabilitation for the following reasons:

- The lack of a gold standard for neck rehabilitation for schoolboy rugby players.
- No cost effective neck rehabilitation programme could be found.
- During the literature search no study could prove the effectiveness of a neck strengthening programme in the reduction of cervical spine injuries or the prevention of long-term early degenerative changes in the cervical spine could be found.

When developing a therapeutic exercise programme which includes the acquiring of new skills and movement patterns the neuroscientific basis for human movement, motor learning and neuromuscular control should be well understood. These concepts will be explained in more detail in the following section.

4.8.2 Neuroscience

The last decade of the 20th century was named the decade of the Brain and consequently the Neuroscience fraternity named this the decade of Cognitive Neuroscience (Albright *et al*, 2000). The importance of the brain in all fields of healthcare and education was emphasised during a recent International Federation of Orthopaedic Manual Therapists (IFOMT) held in Cape Town, South Africa March, 2004. Physiotherapists realised the importance of not treating the patient only from C1 inferiorly but to consider the involvement of the brain for every treatment technique used. Noakes (2004) stated that even fatigue is a perceived function of the brain. The athlete performs within the limits of the heat production of his body, drawn from past experience, so as not to suffer heat stress.

Albright *et al* (2000) quoted Ulric Neisser who in 1967 said the following:

“the world of experience is produced by the man who experiences it...There certainly is a real world of trees and people and cars and even books, and it has a great deal to do with our experience of these objects. However, we have no direct immediate access to the world, nor to any of its properties ... Whatever we know about reality has been mediated not only by the organs of sense but by complex systems which interpret and reinterpret sensory information.”

Albright *et al* (2000) also said that to study mental operations the scientist had to investigate the flow of sensory information and how the brain interprets this information in memory and action. This implies that each perceptual or motor act has a specific internal representation in the brain. The pattern of activity stores information, in memory, about perceptions and motor acts.

4.8.3 Motor learning

Most movements are learned in early childhood, but the repertoire is increased on a daily basis if so required. According to current knowledge this is possible because each functional motion relies upon perceptuo-motor coordination that involves three major components: the intake of sensory information, the internal coding of this information into a format that is adequate for driving a motor action, and the generation of movements themselves (Jovović *et al*, 1999).

Motor learning is one of the basic principles in physical education and therefore very important in this study since an aim of this study was to educate schoolboy rugby players in the wellbeing of their necks and to take responsibility for themselves. Motor learning is fundamental to human life and consists of neural, physical and behavioural components (Shea *et al*, 1993:8). Hodges (2004) explained the utilisation of motor learning and motor control principles in the development of therapeutic exercise intervention.

4.8.3.1 The Intake of Sensory Information

It is important for any individual to have knowledge pertaining to the relative position of their body and limbs in their surroundings. Sensory systems perform a variety of common tasks and each employs specialised peripheral receptors to respond to the environment. Sensory information could be explained as the input via the sensory part of the central nervous system (efferent impulses) to the sensory information areas of the central nervous system (CNS). For the schoolboy rugby player this could include the sensory input from the sensory information system in any situation that could place the player at risk of injuring his cervical spine (Bloomfield *et al*, 1994:134). Without these sensory information cues the player may not be able to react in a defensive manner in order to protect his neck.

A great deal of sensory information is detected during activities of daily living, for example visual, auditory and proprioceptive input from the joints and muscles. The brain however filters out most of the stimuli to be able to focus on specific selected

tasks. For example when it is expected of a rugby player to run stairs during training he can either block out, or concentrate on the conversation of his team mates around him. If the player is familiar with the stairs, the brain will follow a familiar pattern of movement during the stair running exercise. However, if one of the steps is now deeper than during previous training sessions, the player's brain will detect this change immediately and accommodate. This type of internal feedback is termed *knowledge of performance* (Bloomfield *et al*, 1994:134).

The nervous system contains many different sensory receptors, all of which should function optimally in the schoolboy rugby player for peak performance and the prevention of injury. Sometimes the sensory receptors of the neuromusculoskeletal system are collectively known as proprioception and kinesthesia. Proprioception refers to the sensory receptors in muscles, tendons, joints and the vestibular apparatus whereas kinesthesia is the perceptual experience that is presumed to arise from the proprioceptors' sensation of joint motion or acceleration. The efferent (motor) response to sensory information is termed neuromuscular control (Sage, 1977:88,295). The following section will explain the different sensory receptors and their importance to the schoolboy rugby player in more detail.

Mechanoreceptors

The senses of deep touch, muscle tension and joint position as well as those for hearing and equilibrium rely on the activity of mechanoreceptors. In each case a response is initiated by activation of mechanically gated ion channels (Hudspeth & Logothetis, 2000). Mechanoreceptors function by transducing mechanical deformation of tissue into frequency modulated neural signals (Grigg, 1994). There are three types of mechanoreceptors in peripheral soft tissue namely: Pacinian corpuscles, Meissner corpuscles and free nerve endings. These mechanoreceptors could be either quick-acting, where they discharge when activated and then cease to discharge, or slow acting, where they maintain their level of discharge for as long as the stimulus is present (Hudspeth & Logothetis, 2000).

Muscle Receptors

Muscle spindles detect changes and rate of change in the length of the muscle, whereas golgi tendon organs detect degree and rate of change in the tension within the muscle. Signals from these receptors operate at an unconscious level. Cervical posture and movement are controlled by the tectospinal pathways, linking the cervical and upper thoracic spinal cord and the midbrain. These pathways are important in orientating and organising movements of the head and neck. When a new motor programme is established the premotor area of the cerebral cortex is activated. The motor cortex, basal ganglia, thalamus and cerebellum function together to perform voluntary movement (Snell, 2001:96). The primary motor area has a topographical representation of the body on the surface of the cerebral cortex, with the neck representing a very small area compared to the face and the hand (Snell, 2001:289). The medial zone of the vermis of the cerebellum controls the motor functions of the axial body, the neck, trunk and limb girdles. The lateral zone operates more remotely to provide overall planning of sequential motor movement such as timing and coordination. Overall the cerebellum works as an error detection device of specific movement patterns. It receives information about the body's position in space and the movements in progress, then computes and delivers appropriate signals to the brainstem and effector centres to correct posture and smooth out movements. The cerebellum is important in the process of learning and acquisition of motor skills (Snell, 2001:230-233).

During joint position changes, the length and tension of the muscles surrounding the joint will also change. Muscle spindles in skeletal muscles detect changes in muscle length and rate of length changes and these signals are then transmitted to the CNS via afferent neurons (Clark *et al*, 1985). Muscle spindle afferents project directly to motor neurons via a monosynaptic reflex arch and will trigger a muscle contraction of the agonist when stimulated. Golgi tendon organs are situated in the tendon and musculotendinous junction and aid in regulating muscle tension or load. They are force detectors and function to inhibit muscle contraction when the force exerted by the muscle places the tendon at risk of injury (Grigg, 1994).

Proprioceptors

The role of proprioceptors in the control of movement has been debated over many years. It is generally accepted that one of the functions of proprioceptors is to detect unexpected events and initiate rapid compensatory responses. Over the last decade it has become apparent that proprioceptors have additional roles, especially in the regulation of motor output during unperturbed movements (Pearson, 2000).

Proprioceptive feedback during a motor pattern ensures that the timing and magnitude of the motoneuronal activity is appropriate for the current mechanical state of the moving body parts. This explains why it is so important to perform sport specific training and include patterns of movement that are relevant to the sport. For a rugby player it is therefore important to exercise the neck functionally so that the proprioceptive system in the neck muscles is stimulated continuously for the establishment of appropriate motor patterns.

Without proper proprioceptive input during movement the movement becomes less coordinated. Individuals were asked to perform reaching movements with their arms without proprioceptive feedback. They could perform the movements, but close observation showed a number of abnormalities such as errors in direction and amplitude as well as abnormal trajectories (Gordon *et al*, 1995). Visual information can substitute to some extent for the loss of proprioception. Proprioception could also assist in the shaping of the properties of the neuronal circuits generating feed-forward commands during the learning of movement patterns. The level of muscle activation modifies the stiffness properties of the muscle. Muscle stiffness is the ratio in the change of force to the change in length (Dyhre-Poulsen *et al*, 1991). In essence the more stiffness activated in a muscle the greater the muscle's ability to resist stretch and therefore the dynamic restraint to external loads is improved.

Haggard and Magno (1999) carried a series of experiments out that were based on the Libet paradigm. Libet (1985) performed a series of experiments which lead to the conclusion that every thought, feeling, sensation, or action always occurs objectively before one becomes aware of it subjectively and hence there is no possibility that one

can avoid it. This includes any choice or decisions one makes. Haggard and Magno (1999) showed that the perceived time of movement onset was slightly delayed (by about 75 ms) if the motor cortex is stimulated using transcranial magnetic stimulation, whereas this stimulation causes a far greater delay (of around 200 ms) in the initiation of movement. These observations support the idea that one's awareness of initiating a movement is not derived from sensory signals arising from the moving limb, because such signals are not available until after the limb has started moving. Instead our awareness appears to be linked, at least in part, to a signal that precedes the movement. One signal that is available before a movement is initiated is the prediction of the sensory consequences of the movement. Perhaps one signal that one is aware of when making a movement is this prediction, rather than the movement itself. Sensory feedback from the movement would also be important to check whether the movement was completed as planned.

Perceived motion is not directly related to retinal motion, which illustrates the difference between sensation and perception. The responses of many motion-sensitive neurons in the cortical visual area were found to co-vary with perceived motion rather than retinal motion. This demonstrates that the formation of perceptual neuronal representation is accomplished at early stages in the visual processing hierarchy (Albright *et al*, 2000).

Visual signals can guide actions. Researchers showed that the explicit cellular representation of the space around an individual is situated in the pre-motor cortex. It was also shown that there are pre-motor neurons representing the position of a visual stimulus relative to the observer's forearm. This happened independent of the object's image on the retina. This could orchestrate specific limb movements to stimulus near these body parts (Graziano *et al*, 1994). In the schoolboy rugby player this should be emphasised to train improved peripheral vision. It has been suggested that, in order to simplify the sensory input from the peripheral nervous system, the CNS uses the position of the trunk as a reference for the position of the more distal segments in the limbs (Hodges, 2004). The aim of the study by Hodges (2004) was to determine whether the head and the neck are able to act as a reference frame in the coordination of upper limb movement, in this study the elbow joint specifically. The study showed that a change in the position of the head and neck affects the accuracy of perception of

the position of the elbow joint. This finding is consistent with the hypothesis that the head and neck act as a reference frame in the coordination of upper limb movement in space and suggested that movement of the head and neck during limb movement may introduce error into movement performance. For the schoolboy rugby player it means that he should stabilise his neck and head when performing skills which require coordination of the upper limb.

Receptors in the peripheral receptor fields project to central neurons in an orderly manner. Neurons in various cortical sensory areas have been shown to be far more flexible and mutable in their functional properties than previously thought. Maps are not fixed but are continuously modified by experience and are likely to be involved in perceptual learning (Gratton, 1997). Experiments on visual, auditory and somatosensory cortices have shown an impressive representational plasticity following the manipulation of an area's input (Buonomano & Merzinich, 1998).

4.8.3.2 Internal Neural Coding

Neural coding means that neurons may integrate information from a large number of excitatory inputs ignoring exact timing. In such cases, stimulus attributes are encoded in the mean neuronal firing rate and efficient and reliable processing of sensory data may occur only by means of many different cells representing similar information (Hudspeth & Logothetis, 2000).

According to the literature different areas of the brain have been identified in the literature as being involved in internal neural coding. Movement selection, the planning and internal guidance of a sequence of movements and some aspects of sensory-motor transformations are considered to be important functions of the neuronal circuits of the supplementary motor, premotor and prefrontal areas of the cortex (Pearson, 2000). Considering the role of the parietal cortex in the transformation of sensory signals into voluntary motor commands the following has been a guiding concept. The direction of eye and arm movements to visual targets initially involves a number of coordinate transformations to shift information from a retinal coordinate frame to head, body and world coordinate frames (Kalaska *et al*,

1997). An interesting notion is that information in multiple frames is combined in a distributed manner in parietal neurons to form an abstract representation of space for guiding movements (Andersen *et al*, 1997). This distribution system is considered to assist in specifying how actions are to be accomplished and to provide an interface between cognitive processes and the motor system. The cerebellum is critical in the formation of learned motor responses (Albright *et al*, 2000). The site for this plasticity seems to be situated in the mossy-fibre-parallel-fibre Purkinje cell synapse (Thompson *et al*, 1998). The cerebellar cortex has a special function in the learning of the timing of a movement. This guides the learning into the deep nuclei.

Once the different stimuli have been accepted and recognised an appropriate response must be made. A movement plan is then formulated according to previous similar situations and the outcome evaluated given the specific current situation for the most successful outcome. Any necessary modifications are then made before the movement plan progresses to the effector stage. This function is termed *perception-action coupling* and allows for the faster reaction times needed in many activities. This mechanism of triggered response is thought to be the way practice can improve the speed of reaction needed in many rugby activities where the stimulus is similar but not identical (Bloomfield *et al*, 1994:134).

The player's interpretation of the identified stimuli will depend on what sort of stimuli is expected and any previous similar situations. This form of pattern recognition is stored in the long-term memory. The accuracy of the player's response will be determined by the ability of the player to retrieve information from his long-term memory and then be modified by other centres of the central nervous system. A typical example would be two opposing centres, one experienced and the other a novice. The experienced player will recognise the body and foot position of his opponent as he tries to perform a dummy pass and react accordingly. The novice will probably miss the telltale signs and miss the tackle. The experienced player will also be able to take in more peripheral visual stimuli of the game around him and plan ahead for his reaction following the tackle on the opponent. This experience helps a player to react to a playing situation quickly and allows him to plan ahead and make tactical decisions. The more a player is subjected to a specific impulse to which a

response is learned and laid down in the long term memory, the more the learned response becomes automatic at the subconscious level (Albright *et al*, 2000).

4.8.3.3 Memory

Many different terms are associated with memory and these terms will be discussed in the following section, since each of these terms play a role in the understanding of how the brain learns and remembers a new movement pattern or skill. The therapeutic exercise programme for the correction and rehabilitation of the cervical spine of a schoolboy rugby player is unique and therefore most of the exercises the player will have to learn during the course of his programme will be new.

Declarative and Procedural Memory

Albright *et al* (2000) suggested that memory has at least two major forms, a declarative (explicit) form concerned with the knowledge of what something was about, (a knowledge of facts and events) and a procedural (implicit) form concerned with the knowledge of how to do something (a knowledge about perceptual and motor procedures) (Milner *et al*, 1998). For the purpose of developing an exercise programme for the schoolboy rugby player the procedural form of memory will be very important. This is because the repeated movements of the neck during the course of the exercise programme will ensure memory of these movement patterns to be used with the appropriate visual clues from the environment of the rugby field in order to aid in the protection and control of his neck.

Declarative memory is stored in the medial temporal lobe and the hippocampus. Procedural memory, however, has many components and involves a large variety of neural systems that may be capable of storing procedural memory. Some of the areas identified were the cerebellum for motor learning, the amygdala for fear, habit learning in the basal ganglia and perceptual learning within the sensory pathways (Albright *et al*, 2000).

Long and Short Term Memory

Long term memory differs from short term memory not only in the time span of the memory, but also in the molecular mechanism. Long term memory requires the synthesis of new protein (Yin & Tully, 1996). Cyclic adenosine monophosphate (cAMP), and cAMP responsive transcription factor (CREB) are both critically involved in the conversion of short-term to long-term memory (Albright *et al*, 2000).

The Role of Working Memory in Motor Learning and Performance

It is common belief that during motor skill acquisition the learner passes through stages that are broadly defined by the transformation of declarative knowledge to procedural knowledge (Anderson, 1982). Declarative knowledge is knowledge which can be described, whereas procedural knowledge is which may control behaviour, but which cannot necessarily be described.

When learning motor skills, visual, auditory, proprioceptive, and tactile sensory feedback is available to the performer for appraisal of the outcome of his actions (Magill, 1993). The learner tests hypotheses about how best to perform the skill and uses predominantly visual feedback to assess the success of his performance. This process generates a set of rules, which can be considered as declarative knowledge. Procedural knowledge is generated by continued application of these rules until the movement is successfully acquired and could be released from declarative control.

Both declarative and procedural knowledge are archived in some type of long-term store for future retrieval. The application of declarative knowledge requires the availability of working memory (Baddely, 1986) whereas this is not necessary for procedural knowledge. Working memory is required to make executive decisions based on declarative performance rules and is unsuited to processing the kind of information that comprises procedural knowledge. Typically procedural knowledge is processed automatically unless it is disrupted by the intrusion of controlled processing mediated by working memory (Roberts & MacLeod, 1998).

Maxwell et al (2003) performed three experiments to explore the role of working memory in skill acquisition and performance. Following the experiment they propose an independent, parallel processing mode, which predicts that procedural and declarative knowledge can be acquired separately, and that procedural knowledge does not depend on the availability of working memory, but that declarative knowledge does. In their experiments they either withheld or provided visual and auditory feedback. They suggested that the availability of working memory is crucial to motor performance only when the learner has come to rely on its use.

4.8.3.4 Motor Response

The amount of stimuli used to plan and perform a movement will depend on the amount of attention and concentration devoted to a particular function at a time. To select the most useful information requires the correct allocation of attention. For a rugby player this is extremely important not only to focus on the oncoming opponent, but also to be aware of how the rest of the backline is spaced in order to plan ahead on his response to possibly tackling the opponent and perhaps acquiring the ball.

During this stage the response is coordinated by appropriate muscle recruitment with the correct amount of force production. Central programming in the motor cortex allows unconsciously performing specific learned skills. This allows the player to divert cognitive processes to other areas to perform tactical decisions. In the cervical spine of a rugby player, this could mean that the response of muscle recruitment, learned during practise, could be performed automatically so that this does not influence his concentration on the rest of the game. Coordination of a complex skill that requires activation of different muscle groups is known as a motor programme or engram (Bloomfield *et al*, 1994:134). Any skill which requires a response time of less than 200ms could not be under conscious control since any cognitive response requires a response time of more than 200ms. A feedforward mechanism is thought to control this type of reaction. For example the reaction time of a boxer is less than 90ms. This reaction relies more on a reflex action. The boxer cannot alter the initial reaction, thus he has to practise each punch so that it becomes a reflex action.

Over the past decade it became apparent that motor skill learning, as well as the modification of learned skills, involves many regions of the brain, in addition to the cerebellum (Halsband & Freund, 1993). The primary motor cortex (M1) and the basal ganglia, particularly for the formation of habitual movement, have emerged as some of these regions. The regions involved in the acquisition of motor skills are not necessarily involved in the retention and execution of the learned skill (Brashers-Krug *et al*, 1996).

The cellular and molecular mechanisms responsible for modifying neuronal function are an important aspect of motor learning. Long term potentiation, long-term depression and alterations in intracortical inhibition are all considered potential factors for producing changes in the motor cortex during learning, whereas cerebellar long-term depression is considered to be an important process in a number of adaptive and conditioning phenomena (Ito, 1993).

Nakamura *et al* (1999) showed that the presupplementary motor area (preSMA), rather than the supplementary motor area (SMA), is crucial for learning new sequences. Many neurons were active in the preSMA during the learning of new sequences, but not during acquired sequences. Consistent with these observations, functional neuro-imaging studies on human subjects revealed that with motor skill learning many areas of the frontoparietal cortices were involved. Sakai *et al* (1998) showed that the dorsolateral prefrontal cortex and the preSMA were activated during early stages of learning, whereas more parietal areas were activated in later stages. During motor learning accuracy of performance was achieved before speed of performance. The motor skill, once established, was maintained for a long time, mainly in the form of speed (Hikosaka *et al*, 1995). The student therefore had to perform the exercises with speed during the final stages of phase 3 exercises (Chapter 6:190).

4.8.3.5 Functional Localizing and Sensory-Motor Transformations

During the 90's investigators, with new imaging and single-unit recording techniques were able to define the regions in the CNS involved in movement control more precisely. There is experimental evidence that the M1 neurones encode information related to intrinsic movement variables, such as muscle force and joint torque (Scott, 2000). More recent studies have indicated that a component of M1 neuron activity is related to sensory variables, indicating that the motor cortex is involved in sensory-motor transformations (Shen & Alexander, 1997). Single-unit recording studies in monkeys have shown that the motor cortex is involved in cognitive aspects of movement control. The concept that the motor cortex functions simply to provide focused command signals to drive motoneurons (the old clinical notion of the "upper motor neuron") is clearly a long way from the truth (Pearson, 2000). Neurophysiological studies by Georgopoulos et al (1982, 1983 and 1992) showed that single nerve cells in the motor cortex are excited prior to performing movements in a specific direction and inhibited prior to movements in other directions. These results suggested that the motor cortex is concerned in the general planning of the direction of movement, rather than the details of the load or the muscles that will have to be activated to produce a specific end point. Biological systems control direction of movements at different levels of complexity, from accurately planned movements to reflexes (Georgopoulos *et al*, 1992).

4.8.3.6 Central Pattern Generation

Central pattern generators (CPGs) are the properties of neuronal circuits to generate rhythmic patterns of motor activity (Pearson, 2000). The concept of pattern generation was firmly established with the discovery that almost every rhythmic motor system is capable of generating patterned activity in the absence of afferent feedback. It was later discovered that most CPGs are very flexible in their function in that they can generate a variety of patterns depending on the condition, especially in the presence of different, naturally occurring neuromodulatory substances (Pearson, 2000).

Neuromodulators act to modify network function. They can initiate rhythmic activity, alter the timing and amplitude of the activity and reconfigure the network to produce qualitatively different motor patterns. Most of the described actions of neuromodulators are probably mediated through second-messenger systems without protein synthesis (Pearson, 2000). Neuromodulators could therefore possibly influence the response of a rugby player to perform differently during a match compared to training sessions performance, since other second-messenger systems may be active during the tension experienced whilst playing a match.

Using computer simulated body biomechanics combined with simulating the controlling neuronal network in a model yielded mechanisms of intersegmental coordination and the function of afferent feedback. This analysis highlights the importance of considering the mechanical properties of musculoskeletal structures in the functional analysis of rhythmic motor systems (Grillner *et al*, 1995).

The basic architecture of CPGs is established early in development and mature phenotypes are established. Fine-tuning of network properties depend on extrinsic neuromodulatory signals acting late in ontogeny (Fenelon *et al*, 1998). Therefore it could be reasoned that through range of motion stretches and strengthening movement patterns should be developed early in the young rugby player's life.

4.8.3.7 The Role of the Cerebellum and Basal Ganglia in Motor Learning and Cognition

Compound and sequential movements are not consciously planned because their temporal relationships are too rapid and their magnitude too precise. Movement is thus largely automatic and controlled by background subconscious mental subroutine attention to a particular stimulus or conceptual cue. It is then thought to be sufficient to retrieve from memory an associated specific motor solution or sensorimotor transform (Ghilardi *et al*, 2000). This concept was used in the development of the current exercise programme applied in this study. Sport specific neck movements were included in the programme and the players were asked to imagine these

movements occurring during active participation in rugby, thereby building up cues for strong supporting neck movements in various phases of play.

Hikosaka et al (2002) stated that cerebellar blockade disrupts learning of complex goal-directed behaviour. Cerebellar lesions impair motor sequence learning, but not conditional visuomotor learning or spatial working memory. In contrast, blockade of the dorsal part of the dentate nucleus (which is connected with the primary motor cortex [M1]) does not affect the learning of new sequences, but disrupts the performance of learned sequences. Doya (2000) proposed that learning in the basal ganglia (BG) and cerebellum (CB) is guided by error signals. This error signal may be mediated by midbrain dopamine neurons in the BG and by ascending fibres in the CB. In the BG cortical signals are integrated with reward error signals carried by dopamine neurones in striatal projection neurons: visual and memory responses of caudate neurons were strongly modulated by reward expectations. In the CB, cortical signals and sensorimotor error signals carried by the ascending fibres are integrated in the Purkinje cells. These signals would, at least partly, be relayed back to the cerebral cortex.

Ghilardi et al (2000) found that the ipsilateral cerebellum is involved in limb movements, whereas the ipsilateral dentate nucleus is likely used to store or retrieve implicit memories. Activation of both the anterior and posterior vermis is probably related to executive control of ongoing motor execution.

4.8.3.8 Skilled-Learning-Induced Potentiation in Rat Sensory-Motor Cortex

Monfils and Teskey (2004) investigated synaptic plasticity and memory in the caudal forelimb area of the awake, freely behaving rat. They found that the increase in proficiency of a skilled motor task is positively correlated with a transient unilateral increase in neocortical polysynaptic efficiency on the side contralateral to the reaching forelimb. This appeared to be dissociated from the maintenance of skill proficiency. The change in polysynaptic efficiency returned to levels that are no longer significantly different from baseline after the animal repeatedly trained at

asymptotic levels. In humans it was found that motor-cortical areas shrunk after explicit knowledge of the task was gained, suggesting that there is a transient increase in activity during the learning phase of a task (Grafton *et al*, 1992). Pavlides *et al* (1993) found that the somatosensory cortex is necessary in monkeys to acquire a new motor skill but that it is no longer necessary once the performance of the skill has been acquired.

Monfils and Teskey (2004) in the same study on monkeys also observed partial long-term potentiation (LTP) occlusion in the hemisphere primarily responsible for the skilled behaviour and suggested both a persistent effect of the acquisition of skilled learning and those similar mechanisms may be operating in both skilled-learning-induced potentiation and LTP. This observation also suggested that the neural changes following skilled learning may be mediated by mechanisms similar to that underlying long-term-depression (LTD) induction. Therefore the acquisition of the skill persistently changed the plastic responses of the sensory-motor cortex in subsequent interventions and the baseline level to induce equivalent bidirectional changes in synaptic efficacy was shifted.

The advances in the field of motor learning have had huge benefits for many healthcare professionals involved in amongst others rehabilitative medicine and physiotherapy. The principles of motor learning and motor control overlap in many ways as will be seen during the following discussion concerning neuromuscular control.

4.8.4 Neuromuscular Control

Humans demonstrate a remarkable ability to generate accurate and appropriate motor behaviour under many different and sometimes uncertain environmental conditions. Considering the number of objects and environments and their possible combinations that can influence the dynamics of the motor system, the controller must be capable of providing appropriate motor commands for a multitude of distinct contexts (Wolpert *et al*, 1998). Neuromusculoskeletal control processes may be described by three basic functional mechanisms (Stroeve, 1998):

- A feedforward control process which encodes an appropriate solution to the inverse dynamics of the desired movement trajectory and the forces which act on the musculoskeletal system;
- A feedback control process (reflexive system) which corrects for errors in the representation of the inverse dynamics and accounts for unexpected external forces;
- The intrinsic impedance of a musculoskeletal system, meaning there are reflexive stiffness and viscosity components induced by the muscles and other visco-elastic components of a musculoskeletal system.

Over the past 15 years there has been an explosion of research that has identified deficits in motor control in neuromusculoskeletal pain. These deficits range from changes in the sensory system to changes in feedforward strategies for postural control of the trunk. Many of these research findings have been prompted by clinical observations. Globally the issues of motor control can be viewed from different perspectives. Control of movement and stability require: 1) a sensory system that can detect the status of the system and external and internal factors that act on the body, 2) a system that can interpret the sensory information and compare this to prior experience, predicted consequences, and movement and stability demands, 3) a central motor system that can act on the sensory inputs or motivation to move and plan appropriate strategies to meet the demands of movement and / or stability, and 4) a peripheral system that can act on the commands from the nervous system (O'Sullivan *et al*, 1997; Hides *et al*, 2001).

For the purpose of this study the principles of neuromuscular control form the basis for many of the exercises included as part of the therapeutic exercise programme for the rehabilitation of the cervical spine. The theory is that if the player can control his cervical spine, using movement patterns and dynamic stability, many of the potential risk situations where the cervical spine of a schoolboy rugby player could be injured could in fact be avoided.

4.8.4.1. Models for Neuromuscular Control

There are two varieties of internal models for motor control according to Wolpert and Kawato (1998), namely forward and inverse models. Forward models capture the forward or causal relationship between inputs to the system and outputs. In contrast inverse models invert the system by providing the motor command which will cause the desired response without depending on input to the system. Inverse models are therefore well suited to act as controllers as they can provide the motor commands necessary to achieve some desired state transition.

Bizzi et al (1998) stated that there is an internal model for each of the tasks learned throughout life. This is possible in view of the fact that one conceives the internal model as a newly formed pattern of synaptic facilitation amongst a group of neurons. According to this view it is possible that a given neuron may participate with a different synaptic weight in a number of assemblies, each supporting a different internal model.

Thach (1998) suggested that the motor cerebellum may combine simple movement elements and link them together to a novel stimulus context. An extension of this hypothesis is that the cognitive cerebellum may also combine simple “cognitive units” into larger complexes, by linking them by trial and error learning, to a triggering context. They also proposed that this could be the basis for mental subroutines that form a background to the foreground of our conscious thought. These complex background thoughts are unconscious and automatic. If a situation on the field that requires strategic planning arises, the skilled player would have the foreground awareness to concentrate on the strategy. He will only be aware of body movements and skills required on the field in a global sense. The player would be unaware of using the memory of the moves characteristic of each skill being used on the field. Nonetheless, use of the memory of the moves of each skill would be essential in planning and implementing his strategy. The memory of the movement skills resides in the cerebral cortex, and could be consciously recalled as foreground operation. But, in planning the winning strategy, memory of the movement skills are linked through

to the cerebellum while the intended strategy is present in the conscious foreground with the end results playing out automatically as a subconscious mental subroutine.

These predictions were that a lesion of the cognitive cerebellum would impair a skilled rugby player's ability to:

- Plan future moves.
- Use at a subconscious level the memory of movement skills.
- Learn new strategies.
- Be aware of errors made in planning a strategy.

The player will retain the memory of the movement skills, but will be able to recall them only as conscious foreground mental operation and not as background automatic subconscious mental subroutine (Thach, 1998).

4.8.4.2. Internal Models and Neuromuscular Control

The concept of internal modelling of the motor apparatus has become increasingly prominent over the past decade. This concept states that the physical properties of the limbs and body are represented in the central nervous system (CNS) and that these internal models function to produce feed-forward commands to motoneurons (Wolpert *et al*, 1998). When this system operates optimally these feed-forward commands are all that is needed to produce accurate movement. An explicit feature in these feed-forward models is that learning plays a major role in the development and maintenance of accurate movements. Therefore the rugby player should start developing these feed-forward movement patterns from an early age and maintain the patterns by means of regular exercises through range of motion to refresh the internal representation of the neck area in these internal models. The field of human movement science is therefore in an outstanding position to play a part in the education of motor learning that could assist other professionals in the field of rehabilitative medicine, such as physiotherapists.

4.8.4.3 Feedforward and Feedback Neuromuscular Control

Preparatory muscle activity contributes to the dynamic restraint system by increasing muscle activation levels which in turn increase the stiffness of the entire musculotendinous unit (Morgan, 1977). The result is an improvement in the stretch sensitivity of the muscle spindle system and a reduction in electromechanical delay required to develop muscle tension (Colebatch & McClosky, 1987). Preactivated muscles can decrease reaction time of the muscles, thereby improving dynamic joint stability and therefore compensating for external loads being placed on the system.

Both feedforward and feedback neuromuscular control can enhance dynamic stability if the sensory and motor pathways are frequently stimulated. The importance of improved neuromuscular control in the cervical spine of schoolboy rugby players could therefore be of utmost importance in a prevention programme.

As a hypothesis of abnormal motion segment mobility it could be reasoned that the facet joints of the cervical spine have been subjected to high loads and forces with increased wear and tear of the joint surfaces. Therefore it could be reasoned that the joints are in an early stage of degenerative changes. This could imply that there is already a possibility of deafferentation with resulting decreased sensory feedback from the cervical spine to the CNS. Proprioceptive and kinaesthesia exercises are therefore of utmost importance to improve the sensory information to the CNS. This could result in improved neuromuscular control of the cervical spine with a better dynamic restraint system functioning. It was therefore decided to include proprioceptive and kinaesthesia exercises in the neck strengthening exercise programme of the rugby players.

The exercise programme for the rugby players was named “neck strengthening exercises” for the sake of the schoolboy rugby players, but the investigator fully understands that there are many more components included in the programme than just strengthening.

Sekiguchi et al (2003) studied the differences in recruitment properties of the corticospinal pathways between lengthening and shortening contractions in the human soleus muscle. They concluded that during lengthening contractions, the inhibitory component of the corticospinal volleys was relatively increased compared to that during the shortening contraction. A relative increase of the inhibitory component would be involved in the reduced subliminal fringe of the corticospinal pathway during lengthening contractions. These neural mechanisms would help to avoid reflexive contractions and enable fine motor actions of the lengthening contractions. Lengthening contractions were therefore included in the neck strengthening exercise programme for the schoolboy rugby players to help in strength training through full range of cervical motion in order to promote dynamic stability of the neck (Chapter 6:198).

Response programming refers to the feedback to decide if the response was the correct one, and if not, how to adapt the response for a similar encounter in the future. Fast coordinated movement cannot be described by feedback models alone, because biological feedback loops are too slow and have small gains (Wolpert *et al*, 1998). Two major feed-forward control schemes have been proposed, the equilibrium-point control hypothesis (Feldman, 1966; Bizzi *et al*, 1984) and the inverse dynamic model hypothesis (Kawato *et al*, 1987).

4.8.4.4 Limitations of motor control

The capacity of how much information the system can process at any one time is dependent on each individual. The speed of information processing will depend on whether the person has to deal with the different stimuli in series, one element at a time; or parallel, many elements at the same time. Another limitation is distortion, the extent to which information is lost or stored during the process. This often depends on the amount of concentration or attention the person gives to the process. The schoolboy rugby player should therefore always concentrate when learning the new exercises until such a time as he could perform the exercises without having to think about them (Bloomfield *et al*, 1994:134).

The principles of motor learning and neuromuscular control described above will be implemented in the following section in the development of a therapeutic exercise programme for the rehabilitation of schoolboy rugby players' necks.

4.8.5 The Neck Rehabilitation Programme

As stated in before (Chapter 1:16), rehabilitation could be defined as the restoration of an individual or a part of the body to normal or near normal function after disabling disease, injury, addiction, or incarceration (Mosby's, 2002:1345). For the purpose of this thesis the term "neck rehabilitation" is used to describe the programme which would achieve the optimal neck function necessary for the schoolboy rugby player.

It is essential that players participate in training and conditioning exercises that reduce the risk of injury to the player (Prentice, 2004:6). Exercise interventions have been refined to encompass motor learning principles to train the nervous system to use the spinal muscles in a manner more akin with normal function (O'Sullivan *et al*, 1997; Hides *et al*, 2001).

Following injury to a joint there will always be reduced range of motion. This could be the result of factors such as resistance of the musculotendinous unit to stretch, contracture of connective tissue or some combination of the two. Muscle imbalance, postural imbalance, neural tension and joint dysfunction could also be contributing factors in the loss of range of motion (Prentice, 2004:10). A well designed rehabilitation programme should therefore include the following elements:

- General principles pertaining to the exercise programme to explain the importance of the programme and what is expected of the player;
- Clear pictures of the exercise as well as someone available to explain the exercise in more detail should the player not understand;
- The opportunity to imitate someone when performing the exercises initially;
- Core stability exercises;
- Strengthening, endurance and power exercises;
- Exercises for neuromuscular control;

- Spinal stability and mobility exercises;
- Flexibility exercises;
- Neural tissue mobilising exercises;
- Balance exercises;
- Motivational support to ensure sustained commitment by the schoolboy rugby players to perform their exercises.

4.8.5.1 General Principles for Neck Rehabilitation Programme

Core Stability

The core is defined as the lumbo-pelvic-hip complex where the centre of gravity is located and where all movements begin (Gracovetsky & Farfan, 1986). The core operates as an integrated functional unit within the functional kinetic chain whereby the chain works synergistically to produce force, reduce force, and dynamically stabilise against abnormal force.

The functional kinetic chain rehabilitation strives to improve all the components necessary for the athlete, in this case the schoolboy rugby player, to a higher level of performance. The functional kinetic chain operates as an integrated system and therefore functional rehabilitation must train each component of the functional kinetic chain for optimal results. For the current study the basic core stability exercises were included during phase one of the rehabilitation programme, and during phases two and three constant reminder was given to the player to remember core stability during the exercise. It was however not within the scope of this study to include comprehensive final rehabilitation of the core.

Control strategies used by the central nervous system (CNS) to maintain stability of the trunk are complicated by the complex arrangement of muscles and the multiple forces acting on the trunk as a result of normal body movement (Hodges *et al*, 2001). The complex arrangement of muscles of the trunk can control trunk motion directly and indirectly. Superficial trunk muscles have been found to act in a manner which varies between limb movement direction, and is consistent with the initiation of

preparatory trunk motion prior to symmetrical bilateral upper limb movement (Hodges *et al*, 1999). In contrast, the response of transversus abdominis is not influenced by the direction of the reactive moments and may contribute to a non-direction specific control of trunk stiffness (Hodges & Richardson, 1997). In addition, generation of intra-abdominal pressure by transversus abdominis is thought to contribute to spinal control (Cresswell *et al*, 1992). For the schoolboy rugby player core (trunk) stability is vital since most skills required for rugby include limb movements which should be performed from a stable base.

Some of the exercises included in the exercise programme are based on Pilates movement patterns (Chapter 6:185). The Pilates method is a comprehensive body-conditioning method directed towards the development of both the body and the mind of the individual. Perhaps the major tenet of the Pilates method is the concept of centring. Joseph Pilates believed that all the muscles of the body should be strengthened and stretched, but he felt that the emphasis of the exercise programme should be on the centre, or core, of the body. He referred to this as the powerhouse of the body (Muscolino & Cipriani, 2004a). The concept of centring is not only to create a strong structural powerhouse, but also a flexible one, and Pilates said that the integrity of the functioning of the body would subsequently improve. He said “a man is only as old as his spine is inflexible”. The Pilates method affects the powerhouse in three major ways:

- Posterior tilt of the pelvis;
- Lengthening of the spine;
- Increasing the tone or structural integrity of the abdominopelvic cavity.

The powerhouse is the core of the body and therefore having a strong powerhouse creates a stabilised core from which the muscles can contract (Muscolino & Cipriani, 2004b). The authors further state that the sharp and precise focus of the Pilates method is to require the patient to use a concentrated mind to precisely control this posture powerhouse, all the time breathing to maintain proper blood flow to “bath the tissues with nutrients and drain away the waste products of metabolism” (Chapter 6:185).

Trick Movements

The intended exercise programme should have very specific guidelines for the player that should be written and explained in such a way that the player can understand and implement the exercise with the help of his coach if necessary, to prevent or at least reduce possible trick movement especially in the case of the stabilisers. If the central intersegmental stabilising muscles are weak, the global movers will take over the movement and this will lead to a muscle imbalance of the stabilisers versus the movers. Generally the movers will become less flexible if they have to perform as stabilisers and this will lead to the development of reduced range of motion of the cervical spine. It stands to reason that in a pain free schoolboy rugby player who actively participate in rugby and has had a training programme which includes neck strengthening exercises the level of exercises should be that of final sport specific exercises.

Pain

According to Giffen and Stanish (1993) the intensity of the exercise should be such that pain or discomfort is experienced in the last set of 10 repetitions during a total of 30 repetitions. Extreme pain throughout the entire 30 repetitions is a sign of too much force applied. They also suggest the importance of task specific exercises. The players were advised that in the event of severe pain to return to the previous phase of the programme.

Imitation

Heyes (2001) studied the causes and consequences of imitation in learning. He stated that research on neural mechanisms of imitation focused on the hypothesis that areas 44 and 45 of the left inferior frontal gyrus (IFG) are specialised for imitation. Evidence of a link between the left (IFG) and imitation has come from functional magnetic resonance imaging (fMRI). Heyes (2001) also highlighted the recognition hypothesis proposed by various other investigators, which suggested that the left IFG mediates body movement recognition which is achieved via activation of the

premotor and motor areas, and is involved in imitation only on those occasions, or to the extent, that imitation is accompanied or mediated by movement recognition. The exercises of the neck strengthening programme were therefore demonstrated to the players and then taught to the captain of the team, who then performed the exercise programme before the start of each training session. The description of the exercises is accompanied by photographs of each exercise by a model to remind the player of the exercise.

Sensory prediction may underline the ability to prepare and imagine movements. It is well established that imagining a movement and preparing to move, activate a subset of brain regions that are also activated by executing a movement (Naito *et al*, 2002). A recent functional magnetic resonance imaging (fMRI) study scanned subjects while they executed movements or imagined making the same movement. A direct comparison between brain activity during imagined and executed movement revealed that imagining movements activate the left posterior and inferior parietal lobe to a greater extent than executing the same movement. The schoolboy rugby players were therefore asked to imagine using many of the movement skills learned in the therapeutic exercise rehabilitation programme during their participation in the game of rugby. The reasoning behind this is that they may develop movement pattern programmes which they may then use in their game.

Enhancing Motor Learning through External-Focus Instructions and Feedback

Shea and Wulf (1999) replicated results by Wulf *et al* (1998) in demonstrating more effective learning if the learner's attention was directed to an external effect of their movements, rather than their own body movements. Similar advances were seen under feedback conditions. This suggests that the feedback given to performers during practice can be more effective if it directs their attention to the effects of their movements instead of the movements themselves. This concept was implemented in different exercises during stage 1 through 3 of the neck exercise programme given to the rugby players.

Eye Position during Cervical Spine Rotation

The aim of a study by Bexander et al (2004) was to develop a technique for the insertion of intramuscular electrodes into obliquus capitis inferior (OI), cervical multifides (MF) and splenius capitis (SC) with ultrasound guidance, to investigate the activity of the deep and superficial neck muscles during cervical rotation, and whether eye position influenced the activity of the neck muscles during cervical rotation.

The results showed, as expected, that the right sternocleidomastoid (SCM) and SC were active during right rotation. In contrast the tonic and non-direction specific activity of OI and MF were consistent with a contribution to control the cervical spine, rather than producing torque. The finding that SCM activity was influenced by gaze direction indicated that intra-orbit eye position may be important during rehabilitation of cervical spine muscle activity and movement. Furthermore the effect of eye position on neck muscle activity may affect the accuracy of postural control of the neck. It was thus decided to integrate eye position in the rehabilitation programme for the study population.

4.8.5.2 Strength Training

Many of the exercises were designed to simultaneously improve both muscle strength and neuromuscular control.

A functional rehabilitative strengthening exercise programme should involve exercises in all three planes of space, concentrating on a combination of concentric, eccentric and isometric exercises, designed to increase strength through a full multiplanar range of motion, and to improve core stabilisation and neuromuscular control (Prentice, 2004:12).

When first performing a movement against resistance the movement is uncoordinated in the contributions of the agonist, antagonist and the stabilisers. With repeated movements the coordination improves and strength increases. This is the most dominant neural adaptation process during the first six to eight weeks of a resistance

training programme. Therefore it was decided to increase the duration of the study to 12 weeks to confirm that the initial improvement in the outcome of the players was maintained over a longer period.

Progressive resistive exercises are the most commonly used in a rehabilitation programme. Progressive resistive exercises use isotonic contractions in which force is generated while the muscle is changing in length. The isotonic contraction may be used either as lengthening or shortening contractions (Prentice, 2004:10). Core stability is essential in developing functional strength. Core stability functions to stabilise the entire kinetic chain during functional movements (King, 2000).

Muscle strength can be defined as the amount of force (or torque) a muscle group can exert against a resistance in one maximal effort. The definition of power is the ability of the muscle group to produce high levels of work (the product of force and the distance through which the force acts) quickly. Power is the result of speed and strength (Bloomfield *et al*, 1994:110 and Faulkner *et al*, 1993).

The importance of resistance training in the form of resistance training and plyometric training in sport for the improvement of performances has been shown in various studies according to Bloomfield *et al* (1994:111). These authors also referred to a study by Atha (1981) that shows that an isometric contraction of the forearm flexors takes 1.6 seconds to develop maximum tension and for the leg extensors this time are even longer. The delay is due to the fact that all the muscle fibres for the appropriate muscle must be recruited and fired at their maximum rate and the muscle and tendons may need to stretch prior to force development. Thus in the neck the ability to coordinate and control movement for example during the tackling phase of play is not influenced by strength alone. Therefore, it could be reasoned that rugby players must be strong and also able to generate high levels of force over relatively short periods of time to facilitate the stabilising of the cervical spine during a period of increased risk, such as a scrum or tackle.

Sterling *et al* (2003) investigated motor system dysfunction following whiplash injury. As has been stated before, some of the injuries sustained in rugby players closely simulate a whiplash type injury. They found evidence of early changes in

motor function following whiplash injury. These changes were apparent within one month of the injury, and occurred not only in those reporting moderate to severe symptom at three months, but also in subjects who recovered and those with persistent mild symptoms. Deficits in range of motion were present within one month of injury in all the subjects. Most subjects regained normal range of motion within the first three months of the injury. Increased activity in the superficial neck flexor muscles during the cranio-cervical flexion test (CCFT) is thought to be indicative of alterations in patterns of muscle activation and recruitment, and has been identified in patients with chronic neck pain of both traumatic and non-traumatic origin (Jull, 2000). The study demonstrated that these changes occurred soon after injury and also persisted in the patients whose symptoms resolved during the three months of the study. This was the motivation that the emphasis be placed on motor control for the current study. The method described by Jull et al (2002) for retraining cranio-cervical flexion was used in this study (Chapter 6:186).

Types of Muscle Contractions

If the force developed by the muscle is greater than the load on the muscle, a shortening (concentric) contraction occurs. If the force developed by the muscle and the load are equivalent, or the load is immovable, a fixed length, or isometric contraction occurs. When the load on the muscle is greater than the force developed by the muscle and the muscle is stretched, a lengthening (eccentric) contraction is produced (Faulkner *et al*, 1993 and Bloomfield *et al*, 1994:117).

MUSCLE ACTIONS

The muscle or group of muscles responsible for the action is called the ***agonist or prime mover***. The muscle or group of muscles located on the opposite side of the joint acts to resist the movement and they are called the ***antagonists***. The muscles that act to stabilise the skeletal structures during a movement are called the ***stabilisers or fixators***.

CERVICAL SPINE STABILISING EXERCISES

Kettler et al (2001) simulated cervical muscles in six human cervical spine specimens by fixating cables at the insertion point of the muscles. One anterior and two posterior pairs of intrinsic cervical spine muscles were simulated. They found that these simulated muscles strongly stabilised intact and injured cervical spine specimens in all loading directions. They concluded that the omission of the small intrinsic muscles of the cervical spine did not seem to have any effect on the overall stability of the cervical spine. Since the coactivation patterns of the intrinsic cervical spine muscles are not known the simulated scenario does not fully reflect normal physiological motion. These findings correlate well with a study of lumbosacral specimens performed by Wilke et al (1995).

Laurén et al (1997) suggested that lack of strength, coordination and effective coupling of muscles could cause major problems in postural stability. They also state that muscle forces should be generated at exactly the right time, with the correct amplitude, and that impairment in this reflex chain could cause delayed muscle reaction resulting in ineffective functional stability.

A relationship between low back pain and impaired psychomotor control has been observed in a cross-sectional study (Luoto *et al*, 1995). Luoto et al (1996) found that impaired psychomotor control in chronic lower back patients was reversible with successful rehabilitation. In the current study the stability of the cervical spine is essential in the management of the cervical spine in rugby players. Therefore the prescribed stability exercises should be such as to promote the correct sequencing of the stabilising muscles prior to the activation of the mobilisers. When working on the stability of the cervical spine at any range of motion, it is important to remember that the intersegmental muscles should be recruited first before the global movers come into play. If the intersegmental muscles are not strong enough the global muscles will take over the stability function and this reduces the efficiency of the stabilising system. Much research has been performed on the lower back concerning the training of the intersegmental stabilisers. These are the lumbar multifidi muscles as well as the transversus abdominus muscles (Hodges, 2004). No such research has been conducted

on the cervical spine. Therefore it was decided to use the same principles and adjust them for the cervical spine.

DYNAMIC STABILISATION

The aim of dynamic stabilization of the necks of these rugby players is to create and encourage preparatory agonist / antagonist coactivation around the cervical spine motion segments. Efficient coactivation restores the force couples of the muscles surrounding the motion segments of the cervical spine and this will balance the forces acting on the cervical spine thereby increasing joint congruency with a resulting in reduced load on the static structures of the motion segment. (Chimura *et al*, 2002).

Movement of the eyes and head are intimately related. Eccentric intra-orbit eye position results in asymmetrical activation of neck musculature, favouring head rotation towards the direction of gaze (Coppieters *et al*, 2004). This asymmetrical activation pattern presents a potential conflict when a symmetrical activation is required for stability of the head and neck. The authors studied whether postural control of the head and neck is compromised when the coupling between head and eye muscle activity is in contrast with the postural command. They found that eccentric intra-orbit eye position resulted in decreased ability to stabilise the head when postural control was simultaneously challenged. The decreased stabilising ability was present at both relatively small and larger magnitudes of eye eccentricity. The increased rotation was always in the same direction as the direction of gaze, which was consistent with the hypothesis that postural control is compromised as a result of a conflicting motor command associated with eye-head coordination. The reduction in postural control suggested that conflicting tasks may present a risk factor for musculoskeletal pain and / or injury. For the rugby player this means that he should always attempt to face in the direction where the phase of play is likely to come from.

Resistance Training

During the design of the therapeutic exercise programme it was decided to make use of progressive resistance training as the main focus on the strengthening part of the programme. It is important to exercise a muscle in the posture for which it is being trained (Bloomfield *et al*, 1994:121). In the case of the rugby player the exercises should be performed with the neck in a position horizontal to the playing field since this is the position of the player during a scrum or ruck and maul situation. During the tackle phase of play, in the event of the player performing the tackle on an opponent, the neck is also in a horizontal position. When the player is being tackled he may be upright, but as he falls his neck will probably be in the horizontal position. The added importance of this is that the player will have to contend with the added effect of gravity with the neck in the horizontal position. The force calculated for the work that the neck must perform, needs to be the weight of the head that the neck must maintain against gravity, plus any force exerted by the opponent or the strain on the neck in the scrum.

Traditionally the exercise programmes given to strengthen the neck muscles of rugby players concentrated on isometric exercises with the head in a neutral upright position. This may be considered a safe basic neck exercise, but the programme should progress to more sport specific exercises for the rugby player. During the game of rugby the stresses of the cervical spine is such that the spine should be able to maintain stability throughout the entire range of motion. For example, in the event of the scrum collapsing, the cervical spine may be subjected to end of range motion of one or more of the movements of the cervical spine. The first important requirement of the player must be full available range of motion with normal patterns of motion, therefore no dysfunction. Considering that biomechanical dysfunction was found in rugby players (Steyn, 2002), the following could be theorised: the player is in a position of slight flexion with couples rotation and side bending towards the side of the impact during a tackle manoeuvre. During the impact the force from the opponent's body is transmitted through the neck of the tackling player with the result that in the rotated position the player's neck is forced into side bending to the opposite side. This is the movement of restriction found in the tested rugby players and

therefore the possibility of an injury is enormous. It thus stands to reason that during the exercises programme the dysfunction should be corrected first, and then the player should be strengthened with through range of motion exercise to ensure stability throughout the range of motion, as well as at the end of available range.

THE OVERLOAD PRINCIPLE

For a muscle to improve in strength it must work harder than what it is accustomed to (overloaded). Without overloading, muscle strength will be maintained at the level to which the muscle is accustomed, but no increases in strength will be gained. In progressive resistance exercises muscle strength is increased through muscle contractions that overcome some fixed resistance, such as Theraband or Surgical Tubing. Prentice suggested that Theraband and Surgical Tubing could be used for resistance in a rehabilitation programme against movements in all three planes of space, such as using PNF (proprioceptive neuromuscular facilitation) patterns of movement. The designed rehabilitation programme therefore included both Theraband and Surgical tubing using the PNF movement pattern of the neck against resistance (Prentice, 2004:144-146).

THE RATE OF MUSCLE CONTRACTION

The rate at which a muscle can contract depends on the number of sarcomeres in series that the muscle possesses. The greater the number of sarcomeres in any given length of muscle, the more actin and myosin will be simultaneously sliding past one another and thus the greater the rate of muscle contraction. According to Bloomfield et al (1994:115) researchers have reported that the maximum shortening velocity of bundles of fast twitch fibres are three times greater than equivalent bundles of slow twitch fibres.

A high percentage of fast twitch fibres tend to be associated with good performance in strength, speed and power, but with relatively poor performance in endurance. The vast amount of research according to Bloomfield et al (1994:115) have demonstrated that the relative percentage of fast and slow twitch muscle fibres are genetically determined and varies little in response to training. Fast twitch fibres may improve

their endurance ability, but they will never be fully functional slow twitch fibres and the reverse also applies (Bloomfield *et al*, 1994:115).

MOTOR UNIT RECRUITMENT

Individual muscle fibres do not operate individually but are innervated by motor neurons from the spinal cord. A motor unit includes the motor neuron and all the muscle fibres it innervates. Each muscle consists of between 100 and 1000 motor units. In a small muscle that requires fine precision work, one motor unit may innervate as little as three muscle fibres. In a large muscle such as gluteus maximus as many as 800 muscle fibres may be innervated by one motor unit. All muscle fibres in the same motor unit will consist of the same type of muscle fibre, that is fast or slow twitch fibres. Typically slow twitch motor units innervate between 10 and 180 muscle fibres and fast twitch motor units innervate between 300 and 800 muscle fibres. As muscle tension increases the smaller slow twitch motor units are recruited first and then the larger fast twitch motor units. The increase in tension will first be produced due to an increase in the firing rate of the slow twitch motor units, and additional tension is then created by the recruitment of progressively larger fast twitch motor units and an increase in the firing rate by these units. This means that when weight training light weight will not improve power since the larger fast twitch motor units will not be recruited (Bloomfield *et al*, 1994:116 and Faulkner *et al*, 1993).

NEURAL ADAPTATION IN RESPONSE TO RESISTANCE TRAINING

Bloomfield *et al* (1994:121) refer to studies by Rasch and Morehouse (1957) and Moritani and De Vries (1979) which stated that following a unilateral resistance programme for one leg an improvement in the strength of the untrained leg was observed. The neural adaptation was believed to occur through disinhibition, motor unit synchronisation and the effect of learning. During a normal isometric muscle contraction there is constant neural bombarding of both the agonist as well as the antagonist. The body has its own negative feedback protection in that injury is prevented to the joint by the antagonist firing when the force production in the agonist reaches a certain level. The Golgi tendon organs in the musculotendinous junction are sensitive to the level of tension in the muscle. These Golgi tendon organs send

inhibitory signals to the motor units thereby preventing recruitment of more motor units. This means that the muscle may be working at sub-maximal levels. In the event of resistance training the body is subjected to repeated high levels of force and the sensitivity of the protection mechanisms may be lowered and the process is then called *disinhibition*. Motor unit synchronisation is the ability of the muscle to synchronise the firing of the various motor units within the same muscle to fire at the same time. This is seen in resistance training (Bloomfield *et al*, 1994:122).

OTHER PHYSIOLOGICAL ADAPTATIONS TO RESISTANCE EXERCISE

The strength of the non-contractile structures, such as the tendons and the ligaments, is increased with resistance training. Furthermore the mineral content of the bone is increased, making it stronger and more resistant to fractures (Alway *et al*, 1988). This could be highly beneficial in the cervical spine of a schoolboy rugby player.

Muscle strength versus. muscle endurance training

Most resistance training experts believe that muscle strength and endurance are closely related (Dudley & Fleck, 1987). It has been suggested that endurance training should be three sets of 10 to 15 repetitions (Prentice, 2004:147).

Neuromuscular Efficiency

The efficiency of the neuromuscular system and the function of the motor in producing muscular force are directly related to muscle strength (McComas, 1994). Neuromuscular efficiency is improved by resistance training in three ways: an increase in the number of motor units being recruited, the rate of firing of each motor unit and the synchronization of motor unit firing (Bandy *et al*, 1990).

Injury during Training

The probability of injury to the muscle is greatest during a lengthening contraction. The force developed in the muscle during a lengthening contraction is approximately

twofold greater than during a maximum isometric contraction. The lowest forces are produced during shortening contractions. Bandy et al (1990) theorised that during a lengthening contraction some of the sarcomeres maintain their length while others are stretched beyond overlap and are injured. Consequently the initial injury is predominantly a mechanical injury to individual sarcomeres. When delayed muscle onset soreness occurs, such as for example following a tough training session at the start of the training season, light microscopy of histological sections of muscle demonstrates significant cellular damage two days or more after the initial injury. Therefore a trained muscle can be defined as one that is not injured by a specific protocol of muscle contractions that previously caused injury. In their study on mice the authors had two groups of subjects performing a series of maximal voluntary isometric contractions followed by either six shortening contractions or six lengthening contractions of the elbow flexor muscles. The training was given 4 times per week for seven weeks. After the first week there were no visible sign that the mice were in pain.

It was therefore decided to use this basis for the development of the exercise programme for this thesis. The schoolboy rugby players will perform the exercises four times a week for at least seven weeks. Initial delayed muscle soreness would be acceptable until conditioning to the therapeutic exercise programme is achieved.

The Risks of Resistance Training in Adolescents

The American Academy of Pediatrics recommended that children and adolescents should avoid the practice of weight lifting, power lifting and body building as well as repetitive use of maximal amounts of weight during strength training programmes, until they reached the Tanner stage 5 of sexual maturity. Reports of epiphyseal fractures resulting from weight training during childhood and adolescence are common but in most cases they have been attributed to improper training techniques. The risk of resistance training is due to repetitive micro-trauma to the musculoskeletal system. Close supervision to ensure the correct execution of exercises is recommended (Armstrong & Welsman, 1997:148-149).

4.8.5.3 Re-establishing Neuromuscular Control

Re-establishing neuromuscular control is a critical component in the rehabilitation of a pathological joint. The objective of neuromuscular control is to focus the player on being aware of his peripheral sensation and processing this information to achieve better motor control and thereby improving his skill. This muscle activity helps the player to acquire dynamic stability of the area, in this instance the cervical spine, and reduces the chances of injury. Mechanoreceptors situated in the soft tissues surrounding the motion segments of the cervical spine, such as the ligaments, muscles, and musculotendinous junctions. Further feedback from sensory receptor input are provided by the mechanoreceptors in the joint capsules, which aid in the protection of the joint by providing mechanical restraints to abnormal joint motion. Tenomusculo-receptors have been shown to contribute to muscle stiffness and this is one of the most important defence mechanisms utilised to provide dynamic stability for joints. Increased muscle stiffness of the muscles of the neck prior to joint loading provides dynamic restraint for the motion segments of the cervical spine. These mechanisms are essential for assisting in protecting the necks of schoolboy rugby players. In the event of joint injury the sensory receptors in the soft tissues surrounding the injured area could be damaged resulting in deafferentation. This results in a disruption of feedback to the central nervous system and subsequently the reflexive stabilising strategies will no longer function optimally. Joint injury therefore not only reduces the mechanical stability of the joint, but also diminishes the dynamic stabilising and restraint system of the motion segments, in this case the cervical spine. The cervical spine of a rugby player will therefore be compromised following injury to the facet joints and consequently he will be unable to maintain dynamic stability of the cervical spine. Rehabilitation of the pathological joint should address both the feedforward and feedback mechanisms of neuromuscular control for joint stability. Traditionally rehabilitation programmes concentrated on passive physiological movements without paying much attention to accessory movements (Prentice, 2004:100-103).

Smethurst and Carson (2001) studied the effects of practice on the maintenance of a coordinated pattern as the movement frequency was scaled. Eleven volunteers were

asked to perform a bimanual forearm pronation-supination task. They found that practice increased the stability of a to-be-learned coordination pattern. This is reflected in an increased tolerance to frequency-induced transitions. They suggested that during learning the natural coordination tendencies of the system are suppressed and become completely destabilised.

According to Prentice (2004:105) the following elements should be included in an exercise programme to re-establish neuromuscular control:

- Open and closed kinetic chain activities;
- Balance training;
- Eccentric and high repetition / low load exercises;
- Reflex facilitation through reactive training;
- Stretch-shortening activities;
- Biofeedback training.

4.8.5.4 Closed Kinetic Chain Exercises

Axial load is created during closed kinetic chain exercises and this maximally stimulates articular receptors, and the tenomuscular receptors are in turn stimulated by the subsequent changes in muscle length or tension (Wilk *et al*, 1996). Performing open or closed chain exercises under weighted conditions will further increase the level of difficulty of the exercise and may lead to a training stimulus. Joint loads are resisted and absorbed through preparatory and reactive dynamic restraint through muscle stiffness (Mair *et al*, 1996). Exercises which increase muscle stiffness should therefore be included in the design of a rehabilitation programme and as such was included in the rehabilitation programme designed for this study (Chapter6:196).

4.8.5.5 Proprioceptive Neuromuscular Facilitation (PNF)

REFLEX MUSCLE ACTIVATION

Melvill-Jones and Watt (1971) suggested that stretch reflexes are superimposed on preprogrammed muscle activity from higher centra. Therefore preparatory and

reactive muscle activation may improve dynamic and functional stability in a compromised joint. Ballistic end of range stretches against the resistance of Theraband or Surgical Tubing was therefore included in the design of the rehabilitation programme.

DISCRIMINATIVE MUSCLE ACTIVATION

A critical component for balancing and coordinating joint forces is unconscious control of muscle activity. This highlights the importance of restoring the force couples of the agonist and antagonist muscles surrounding the compromised joint, in this case the motion segment of the cervical spine. Initially this may require conscious control of the muscles before unconscious control will develop.

Because injuries to the cervical spine normally occur at the end of range of motion it is important to include strengthening exercises at the end of range of motion.

Proprioceptive neuromuscular facilitation (PNF) is an approach to therapeutic exercises based on the principles of functional human anatomy and neurophysiology (Burke *et al*, 2000). These techniques have long been advocated in the rehabilitation of injuries for increasing strength, flexibility and range of motion (Johnson, 2000 and Stone, 2000). PNF techniques are also beneficial in the improvement of neuromuscular control and should form part of any rehabilitation programme.

THE NEUROPHYSIOLOGICAL BASIS FOR PNF:

Most therapeutic exercise principles can be attributed to the work of Sherrington (1947) and Lloyd (1946), who first described the concepts of facilitation and inhibition. When an impulse travels down the corticospinal pathway or an afferent impulse from peripheral receptor travels up to the CNS, an impulse volley occurs, which results in the discharge of a limited number of specific motor neurons, as well as additional surrounding (anatomically close) motor neurons within the subliminal fringe area. An impulse causing the recruitment and discharge of additional motor neurons within the subliminal fringe is said to be facilitatory. Any stimulation which

causes motor neurons to drop away from the discharge zone in the subliminal fringe is said to be inhibitory (Stone, 2000).

For this study the basic PNF pattern for the cervical spine was used, but without the researcher being present to elicit the stretch reflex, an absolute PNF process could not be achieved.

4.8.5.6 Stretch shortening activities

Simulated positions where the cervical spine of the rugby player would be vulnerable must be used where reactive muscle stabilisation is necessary. This will restore the dynamic muscle activation necessary for functional stability. It may be argued that placing the cervical spine in a vulnerable position during exercising could place the cervical spine at risk of injury. However, if this is done in a controlled manner with slow progression, neuromuscular adaptation will occur that would permit the rugby player to participate with confidence that the dynamic stability of his neck is trained to maximally support his neck. This is very important for the young rugby player since this confidence would promote a feeling of self-efficacy, shown to be very important for the belief systems created early in life, and possibly having an effect on the pain behaviour mechanisms later in life (Prentice, 2004:105) (Chapter 6:208).

4.8.5.7 Reactive Neuromuscular Control

Reactive neuromuscular training focuses on stimulating the reflex pathways from the articular and tenomusculo-receptors to the muscles. The aim of these exercises is to elicit stabilisation by means of joint perturbation. This was included in the exercise programme by using the closed kinetic chain exercises of the cervical spine and adding perturbation from another player who is trusted, so as to reduce the risk of another player causing an injury due to foolishness (Ihara & Nakayama, 1986). A crucial element of the dynamic restraint mechanism is reflex-mediated muscle activity and this should be included in a rehabilitation programme to achieve functional stability of the joint. The exercise programme should also include functional sport specific exercises to promote reactive neuromuscular control. It was decided that a

schoolboy rugby player should be able to balance his own body weight on his head since his neck could be subjected to this during participation in the game.

4.8.5.8 Plyometrics

In sport success in most activities is dependent on the speed at which muscular force or power can be generated. The main purpose of plyometric training is to heighten the excitability of the neuromuscular system. Any exercise that uses the myotatic stretch reflex to produce a powerful muscle contraction is plyometric in nature. Plyometric exercises train specific movements in a biomechanically correct manner and therefore the muscle ligaments and tendons are strengthened in a functional way (Prentice, 2004:226). Most literature on plyometrics is on the lower quarter (limb). No plyometric exercises could be found for neck muscles. The principle of using a repeated series of stretch-shortening cycles could be adapted for the neck muscles of rugby players to promote power movements in shortened periods of time. This principle was used with most of the exercises during the final phase rehabilitation so that exercises were performed with speed.

The time required between the yielding eccentric muscle contraction and the initiation of the overcoming concentric contraction is decreased with plyometric training. Normal movement is seldom initiated from a static posture, but is rather preceded by an eccentric prestretch that loads the muscle. The physiology of the stretch-shortening cycle can be broken down into two components, namely proprioceptive reflexes and the elastic properties of the muscle fibres. Combined, these two components produce a movement response. Effective plyometric training relies more on the speed of the stretch than the length of the stretch. Emphasis should be on shortening of the amortization phase. If the amortization phase is slow, the elastic energy is lost as heat, and the stretch reflex is not elicited. The faster the player is able to change from the yielding eccentric work to overcoming concentric work, the more powerful the response.

Specificity is the key to the design of a plyometric training programme. The cervical spine of a schoolboy rugby player will be subjected to various stresses and strains and

fast reacting neck muscles could be of great benefit. This should help to ensure that the neck is prepared to accept the stress that could be placed upon it during participation in the game of rugby.

Elements of plyometric training:

- Adequate eccentric muscle strength (Surgical tubing resistance exercises);
- Stability of the neck muscles (shoulder and head stand);
- Dynamic movement testing (PNF movement pattern);
- General and specific testing (spinal mobility and neck muscle stretches).

All of these above elements were included in the design of the rehabilitation programme for the schoolboy rugby players except for the biofeedback training. The reasoning behind this exclusion was that biofeedback could not be performed in a cost effective way, and one of the aims of the programme was that the exercise programme should be accessible to all schoolboy rugby players with relative low cost.

4.8.5.9 Sport Specific Training

Bloomfield et al (1994:111) stated that there are many studies that have shown an improvement in strength following resistance training with no improvement in dynamic sporting performance. Therefore an exercise programme for the strengthening of the neck muscles in rugby players should include dynamic sport specific exercises and not static isometric exercises as is the current trend.

Functional progression forms another element of a well balanced exercise programme. This involves a series of gradually progressive activities designed to prepare the player for functional movement patterns for rugby. The skills necessary for a strong stable cervical spine are broken down into smaller movement patterns and gradually progressed until the final phase of strengthening where the components are combined for functional skills for the neck of a schoolboy rugby player.

As stated previously it is very important to adapt an exercise programme to be sport specific. The exercise should be performed in a manner very specific to the competitive action (Bloomfield *et al*, 1994:127). Rasch and Morehouse (1957) as referred to by Bloomfield *et al* (Bloomfield *et al*, 1994:127) showed that isometric strength training performed in an upright posture resulted in large increases in muscle strength in this position but had very little effect on similar exercises performed in the supine position. The authors concluded that to maximise performance gains the velocity of the movement, range of motion, movement pattern, body posture and type of muscle contraction should correspond closely to the competitive performance. For the purpose of this study the following exercises were developed by the researcher to closely correspond to the above guidelines for sport specific exercises. The further uniqueness of this study was to correct the biomechanical dysfunction in the schoolboy rugby player and following the correction to retrain and strengthen the cervical spine to maintain this correct position.

McClure *et al* (1998) found that axial rotation showed much greater flexibility and lower tolerance for applied torque, compared to flexion and lateral bending. They proposed that one possible explanation for this was muscle orientation. Most cervical muscles are aligned vertically and therefore designed more to resist flexion and lateral bending, and not much to resist rotation. These authors also suggested that the lower torque tolerance was due to the pain sensitive structures undergoing more stress, perhaps because of the lack of muscular resistance. This motivated the inclusion of rotational strengthening exercises in the therapeutic exercise rehabilitation neck programme. This is important because of the increased risk of facet dislocation during combined flexion rotation movements.

4.8.5.10 Skill

Bloomfield *et al* (1994:129) refer to Higgins (1991) whom stated that a skill can be defined as the accuracy, consistency and efficiency of movement deployed). In other words the desired outcome of the motor task has to be achieved (accuracy) in a high proportion of attempts (consistency) and with the minimal amount of physical energy (efficiency). Once a movement is programmed it then takes repeated attempts to

develop the pattern into a skilled movement. For learning to occur there must be memory of the particular skill to allow repetition and refinement. This was thought to be controlled by the part of the cortex concerned with long-term memory. Retrieving the information from long-term memory is the final phase in the execution of the skill. The more a player practises a skill the faster the skill is retrieved from long-term memory. In addition to this, if a second activity performed is similar to the first, it is thought that some learning is transferred between skills, thus speeding up the learning process. This approach is called variable practice. Feedback from the teacher to the learner is very important in learning a new skill and this should be used by all the members of the coaching team to correct scrumming, loose rucks and mauls as well as in tackling techniques in order to promote the prevention of cervical spine injuries (Shea *et al*, 1993:207).

Young and Marteniuk (1998) found that subjects who acquired stereotypic muscle-torque patterns during late learning of a multi-articular kicking task performed kinematically invariant movements by producing muscle torque patterns which were invariant both within and between blocks. However, decrements in noise components for the initial 25 % of the movement were masked by increases in the latter 75 %, presumably due to feedback control. Although there were small inter-subject differences in motor patterns, each subject consistently used the same motor patterns.

There was a progression, or homing in, until the preferred movement patterns were selected, thus the central nervous system systematically made adjustments to motor patterns, perhaps by reinforcing synaptic connections (Loeb, 1993). Therefore as movement patterns are learned, the speed and accuracy of the movement pattern improves and the movement pattern can be performed with speed and accuracy. It was therefore decided to include movement patterns with speed in the final phase of the neck rehabilitation programme (Chapter 6:184).

4.8.5.11 Muscles focused on for the Neck Rehabilitation Programme

The prevertebral muscles

The longus cervicis is the deepest of the prevertebral muscles and lies on the anterior surface of the cervical column from the superior arch of the atlas to the third thoracic vertebra. Anatomically, it consists of three sets of fibres, namely the oblique descending set which is attached to the anterior tubercle of the atlas to the anterior tubercle of the transverse processes of C3 – C6 by three or four tendinous slips; the oblique ascending set attached to the bodies of T2 and T3 and to the anterior tubercles of the transverse processes of C4 – C7 by three or four tendinous slips, and the longitudinal set lying deep to the former two sets and just lateral to the midline. Longus cervicis is attached to the first three thoracic vertebrae and the last six cervical vertebrae. Therefore the longus cervicis covers the entire anterior surface of the cervical column. When both muscles contract they flatten the cervical lordosis with resulting flexion of the cervical spine. They are also important in stabilising the cervical spine at rest. Unilateral contraction of longus cervicis produces forward and lateral flexion of the cervical spine ipsilaterally (Kapandji, 2002:221).

Superficial to longus cervicis lies rectus capitis anterior consisting of two bands. The deep band is attached to the inferior surface of the basi-occiput, anterior to the foramen magnum and to the anterior tubercles of the transverse processes of C3 – C6. Bilateral contraction produces flexion of the head on the cervical spine and flattening of the upper portion of the cervical spine. Unilateral contraction causes forward flexion and ipsilateral flexion of the head (Kapandji, 2002:221).

Strengthening of the deep prevertebral muscles of the cervical spine is strongly advocated by various authors (Jull, 2002 and Sterling *et al*, 2003) in the treatment of cervical spine pathologies. Strengthening of these muscles was therefore included in the therapeutic rehabilitative exercise programme for the schoolboy rugby players (Chapter 6:186). An important aspect in the strengthening of the correct movement pattern of cervical spine flexion is that the movement should be initiated with a head

on neck movement, followed by a segmental flexion motion of the cervical spine. If the cervical spine is flexed as a unit, the global mobilisers of the cervical spine are recruited and not the deep cervical flexors.

The Posterior Muscles of the Cervical Spine

The back of the neck is made up of four muscular planes superimposed on one another.

The deep plane, directly adherent to the vertebrae contains the small intrinsic muscles of the suboccipital part of the cervical spine, the cervical transversospinalis and the interspinous muscles. The transversospinalis muscles are closely adhered to the vertebrae and fill the groove formed by the spines, laminae and the transverse processes. They are made up of muscular slips that overhang one another like roof tiles. The muscle fibres run obliquely inferiorly, laterally and slightly anteriorly. The bilateral contraction of these muscles results in symmetrical extension and with a unilateral contraction there is ipsilateral lateral bending with contralateral rotation (the same action as SCM, but on an intersegmental level) (Kapandji, 2002:238).

The semispinalis plane contains the semispinalis capitis and semispinalis cervicis as well as the transversus thoracis, longissimus thoracis and the superior portion of the iliocostalis laterally. Semispinalis capitis forms a vertical muscular band and arises inferiorly from the transverse processes of the upper six thoracic vertebrae from the base of the transverse processes of the lower four cervical vertebrae and from the spinous processes of C7 and T1. Its muscle belly overlies the longissimus capitis and fills up the vertebral gutter. Unilateral contraction of the muscle produces extension with weak ipsilateral rotation and lateral bending. The longissimus capitis, lying lateral to the former, is long and thin and runs obliquely superiorly and slightly laterally and it arises from the lower four cervical and first thoracic transverse processes and is inserted into the posterior border of the mastoid process. Its fibres twist on themselves as its lowest fibres are inserted most medially and vice versa. Ipsilateral muscle contraction of the longissimus capitis produces extension, ipsilateral rotation and lateral bending (a stronger movement than that by semispinalis) (Kapandji, 2002:238).

The plane of the splenius and the levator scapulae consists of splenius capitis, splenius cervicis and levator scapulae. The splenius muscles run from the occiput to the thoracic spine and are attached to the lower six cervical spinous processes, the posterior cervical ligament, the upper four thoracic spinous processes and the interspinous ligament. Its oblique fibres run superiorly, laterally and anteriorly and wrap around the deeper muscles to be inserted as two distinct bands namely the cephalic and the cervical band. The cephalic band of splenius capitis, inserts on the superior nuchal line of the occiput; and the cervical band of splenius cervicis, inserts onto the transverse processes of the upper three cervical vertebrae. Ipsilateral contraction produces the typical movement pattern of the lower cervical spine muscles namely, extension with ipsilateral rotation and lateral bending.

The final plane is the superficial plane and consists of the trapezius and sterno-cleido-mastoid muscles.

As a whole, except for the deep muscles, the majority of these muscles are obliquely inferiorly, medially and posteriorly inclined and produces simultaneous ipsilateral extension, rotation and lateral bending. This is the normal movement pattern of the facet joints of the cervical spine (Kapandji, 2002:230). Therefore to stretch these muscles the cervical spine should be positioned in flexion, rotation and lateral bending to the contralateral side (Chapter 6:199).

The superficially situated sternocleidomastoid (SCM) and trapezius muscles produce extension, ipsilateral lateral bending and contralateral rotation, therefore to stretch SCM and trapezius the neck should be positioned in flexion, contralateral lateral bending and ipsilateral rotation (Kapandji, 2002:230).

During strengthening of the posterior muscles of the cervical spine the movement patterns are those of the PNF pattern of the cervical spine. This includes the movement that starts in neck flexion, ipsilateral lateral bending and rotation (nose to tip of shoulder) and ends in contralateral rotation and lateral bending with extension (nose to ceiling). Resistance is given to the movement in both directions of the pattern (Chapter 6:188).

4.8.5.12 Function of Muscles in Protecting the Cervical Spine

According to Radin (1986) muscles act to lower the bending stress on bone and to attenuate the peak dynamic loads from unprotected impulsive loads that can damage musculoskeletal tissues. The author also states that it is both the degree of applied mechanical stress and the player's response to the load which determines the damage to the musculoskeletal system. The neuromuscular reflexes protect the musculoskeletal structures of the body. Fatigue and not being prepared are the worst situations for possible injury to the body, and the player should not perform coordination and plyometric type exercises when fatigued at the end of a tough cardiovascular training session (Chapter 6:208).

4.8.5.13 Flexibility

Flexibility of a joint or series of joints have been defined as the ability of the neuromuscular system to allow for sufficient movement of the joint or series of joints through full, non-restricted, pain-free range of motion (Humphrey, 1981). In a series of joints, such as the spine, the joints function together as a unit and therefore hypomobility in one joint could affect the rest of the kinetic chain (Chapman *et al*, 1972). Movement is important for spinal health as movement contributes to shock absorption and the dissipation of forces. Furthermore movement is required to minimise energy expenditure. An alternative strategy is for the CNS to utilise activity of the deep muscles as a component of the control of the cervical spine. Although these muscles are not the main contributors to the stability of the cervical spine, they do make a potent contribution.

Elastic Properties of the Muscles and Tendons

During a resisted lengthening muscle contraction the elastic region of the musculotendinous junction is minutely stretched and consequently elastic energy is stored. With the reversal of the movement this stretched region recoils to its original position and during this period some of the stored energy is recovered to produce

kinetic energy that may enhance the movement. Wilson et al (1992) as referred to by Bloomfield et al (1994:124), indicated that flexibility exercises increases the elasticity of muscles and tendons and that this enhances the contribution of elastic energy to the movement. They showed that eight weeks of flexibility training by experienced weight trainers increased the maximum bench press weight lifted by 5 %. It was therefore decided to include a flexibility programme in the neck exercise programme of the schoolboy rugby players to improve the flexibility of their necks and secondly to strengthen the neck muscles.

Both static and ballistic stretches were included in the neck rehabilitation programme of the rugby players. Exercises that stretch the musculotendinous units and the fascia that produces movement of the specific joint will over time increase the range of motion of the joint (Entyre & Lee, 1988). According to Prentice (2004:127) ballistic stretches are more functional and therefore were included in the neck rehabilitation programme (Chapter 6:201). Static stretches are more traditional stretches and can be used effectively in a flexibility programme. The optimal time for the hold period of the stretch has been suggested by various authors as between 15 and 30 seconds and repeated 3 to 4 times (Bandy & Irion, 1994). Furthermore static stretching is a much safer stretching technique and therefore it was decided to use static stretches during phase one and two of the neck rehabilitation programme and ballistic stretches in phase three of the programme. Ballistic stretching is advised for players competing in dynamic activity, such as rugby players, despite the fact that ballistic stretches could cause muscle soreness.

It has been recommended that flexibility can be maintained by stretching at least once a week. However, to see an improvement in flexibility the player should stretch three to five times per week (De Deyne, 2001). Once a particular joint becomes hypomobile and loses its normal arthrokinetics the muscles around that joint attempt to minimise the strain on the affected joint and subsequently some of the muscles become shortened and hypertonic. This in turn affects both the synergists and the antagonistic muscles with a complex neuromusculoskeletal dysfunction resulting (Prentice 2004:132). In the case of the schoolboy rugby players some of the segments of the cervical spine may become hypomobile and this could therefore result in neuromusculoskeletal dysfunction.

Contract-Relax Exercises

McCarthy et al (1997) showed that cervical range of motion could be improved by the use of contract relax stretching, but that the gains in range of motion were lost within a week after the stretches were stopped. Stretching exercises could be considered useful in combination with joint mobilisation and massage techniques to help in the gains in mobility achieved by these techniques. It is, however, important to maintain the stretching programme in order to maintain the range of motion. It was therefore decided to include a contract relax routine in the exercise programme in order to help to maintain the range of motion of the cervical spine, since this is of the utmost importance to provide the necessary range of motion required during extreme scrumming and tackling scenarios. The study by McCarthy et al (1997) does not supply any detail on how long each contract relax cycle was maintained. Clinically the author uses a 10 s contract period followed by a 30 s stretch period repeated three times.

Specific Muscles to be Stretched

The prevertebral scalene muscles have been implicated as the cause of neck pain and therefore it was decided to include them in the stretching part of the exercise programme (Chapter 6:202). If the scalenes contract on one side the cervical spine is lateral flexed and rotated ipsilaterally, therefore in order to stretch these muscles the cervical spine should be moved into contralateral lateral flexion and rotation (Kapandji, 2002:224).

Some concerns have been raised that strength training could negatively influence the flexibility of the muscle. However there is no reason why strength and flexibility training cannot be included in the same programme, provided that the strength training is performed using movements through full range of motion (Schilling & Stone, 2000).

4.8.5.14 Neural Tissue Mobilising Exercises

It is also necessary to stretch the neural tissues of the affected area to allow a holistic programme which is aimed at affecting the entire neuromusculoskeletal system (Butler, 2000:371)

4.8.5.15 Balance

Balance is sometimes thought of as a static process, but in effect it is actually a highly dynamic process with many neurological pathways being activated. Postural equilibrium is the term used to describe balance in broader terms. Postural alignment of joint segments is an effort to maintain the centre of gravity within range of the maximum limits of stability. According to Prentice (2004:157) balance should form an integral part of any joint rehabilitation programme with the aim of increasing the afferent feedback from the injured joint to the central nervous system.

Postural stability involves the complex integration of muscular forces, neurological sensory information from mechanoreceptors and biomechanical information (Blackburn & Voight, 1995). The ability to maintain balance and good posture is essential in the acquisition of the complex motor skills required by a schoolboy rugby player. An exercise programme must therefore include a balance and proprioceptive component.

The Sensorimotor and Cognitive Integration of Gravity

Gravity can essentially be considered to be a force acting both on the vestibular and proprioceptive systems. Signals from the vestibular system, received at a cranio-topic landmark, provide direct information as to the movements of the head in space, in other words as an exocentric reference, without the need for signal transformation (Pozzo *et al*, 1998). Pozzo *et al* (1998) confirmed the generalisation of the hypothesis that head stabilisation, around the direction determined by gravitational force, constitutes a strategy used by the subjects to optimize the control of dynamic equilibrium. The results of their study argue in favour of a central integration of

gravitational force during locomotion, dynamic postural and arm movement reaching tasks. They further propose that integration and central representation means that gravitational force has not only the status of load acting on the limbs' centre of mass, but also constitutes an orientation reference (the vertical direction), giving the basis upon which body orientation in space, proprioception and motor commands are referred to.

On repeated presentation of a visual or dynamic perturbation subjects adapt increasingly rapidly. It was therefore decided to include perturbation exercises in the rehabilitation programme of neck strengthening to improve the reaction time of the players due to dynamic perturbation. Dynamic perturbation because of the nature of the game of rugby forms an integral part of the skills required of a rugby player (Wolpert & Kawato, 1998).

Poor postural performance has been observed in individuals following whiplash injury. This is relevant to the schoolboy rugby player since whiplash type motions are often sustained by the players. Postural stability requires afferent input in order to generate the appropriate torque in maintaining body position, and it has been suggested that injury to the neck and / or the otolith structures that influence afferent feedback may contribute to a loss in balance (Gosselin *et al*, 2004). The incorporation of somato-afferent, vestibular and visual afferent input are the sensory modalities utilized in the assessment of current body position. This results in the maintenance of balance by motor processes coordinating trunk and lower limb muscles into combined postural strategies to decrease body sway and maintain the body within the base of support.

Hodges *et al* (2000) showed that three-dimensional preparatory trunk motion precedes unilateral upper limb movements. The results confirmed that anticipatory postural adjustments involved movements and not rigidification of the trunk. Their study also confirmed that transversus abdominis activity is either not associated with the control of reactive moments or contributes to increased spinal stiffness in a non-direction specific manner. Transversus abdominis may contribute to the generation of spinal stiffness by increasing the tension in the thoracolumbar fascia or by increasing intra-abdominal pressure. It has been argued that feedforward trunk muscle activity

controls the orientation of the trunk to displacement of the centre of mass (Aruin & Latash, 1995). The results by Hodges et al (2000) provide further evidence that trunk orientation is a controlled variable. As a result of this study, it was decided to include basic core stability exercises in the rehabilitation programme of the schoolboy rugby players as well as perturbation during the balance part of the exercise programme (Chapter 6:198,207).

Koskimies et al (1997) showed that balance can be altered in normal subjects by stimulating neck, lumbar or calf proprioceptors by vibration. They also showed that in patients with neck "tension", postural stability was worse than in healthy subjects. This supports the theory that not only neck injury, but also neck pain and muscle tension can alter the sensitivity of neck proprioception. They also stated that the small intrinsic, deep dorsal and suboccipital cervical muscles show a high density of muscle spindles (Peck *et al*, 1984) that are likely to provide the main contribution to neck proprioception. In the deep cervical muscle spindle complex, about one third of Ia afferent fibres originate in muscle spindles that show a high density of B₂ fibres, innervated by tonic gamma motor neurons, which may be primarily involved in muscle tone. This in turn implies that deep cervical muscle fatigue can disrupt postural control.

Gosselin et al (2004) tested the above theory by studying the effect of deep cervical muscle fatigue on balance in 10 healthy college male students. The results indicated that a 25 % maximal isometric contraction of the neck extensors for a 10 to 15 minute duration produced changes in some posturographic parameters. Furthermore this contraction also produced a cervical muscle EMG median frequency spectrum shift towards the lower frequencies. The fatiguing procedure was performed at 35 % of maximum voluntary contraction for a full five minutes with subjects in standing. A large belt was passed around the head, and was attached in front of the subject to a gym training column. Their results supported the fact that cervical muscle fatigue affects balance, but the authors do not provide any rationale to explain this phenomenon. It was therefore decided to specifically strengthen the cervical spine extensor muscles to improve the endurance of these muscles and reduce fatigue.

4.9 Summary

This chapter considered the literature found concerning human movement in general and then motion segment analysis of the cervical spine in particular. The manual therapy and radiological evaluation of spinal motion segments were then discussed. The principles of motor learning and neuromuscular control were also discussed and the development of the therapeutic exercise programme for the rehabilitation of schoolboy rugby players' necks were motivated by these principles as well as evidence based concepts in rehabilitation.

The following chapter will briefly cover cervical spinal cord injuries in rugby for the sake of completion even though it is not the main emphasis of the current study. The incidence of cervical spinal cord injuries, predisposing factors for cervical spinal cord injuries, mechanism of injury to the cervical spinal cord as well as the role of the physiotherapists and other professionals in the prevention of spinal cord injuries will be discussed.

Chapter 5

Literature review on Cervical Spine Injuries in Rugby

5.1 Introduction

Many serious and debilitating cervical spine injuries occur in rugby players of which cervical spinal cord injury is the most devastating. The laws of the game have changed and players are bigger, stronger and fitter, resulting in larger forces being transmitted during the set scrum, rucks and mauls as well as during the tackling phase of play. The game of rugby earned professional status following the 1995 world cup in South Africa resulting in higher stakes for both the players and the management. Despite the game's professional status there still is no end to the number of cervical spine injuries.

The most devastating of rugby injuries is an injury to the cervical spine resulting in neurological deficit to the player. The prevention of rugby injuries, confined to the cervical spine of schoolboys in this study, is therefore important for various reasons. There have been many studies attempting to reduce or prevent cervical injuries in rugby. Initially there were some positive studies indicating that the number of cervical spine injuries was reduced in schoolboy rugby players (Noakes *et al*, 1999), but in the last couple of seasons there has been a dramatic rise in the incidence of cervical spine injuries in schoolboy rugby players (Jakoet, 2002). Following a spate of severe spinal cord injuries during the first half of the 2002 rugby season in South Africa, Prof. Tim Noakes of the Sport Science Institute of South Africa, and a team of experts held a seminar with the Minister of Sport at the time, Mr. N. Balfour to discuss possible ways of reducing the incidence of spinal cord injuries in rugby players. Noakes suggested the possibility of an intrinsic factor that predisposes a schoolboy rugby player to sustain a cervical spinal cord injury. However, at the time he was not aware of any specific intrinsic factor that could contribute to cervical spinal cord injury.

5.2 Incidence of Cervical Spinal Cord Injuries

The following section will highlight some of the studies conducted on the incidence of cervical spinal cord injuries in rugby players.

One of the studies on the incidence of cervical spinal cord injuries in rugby players was conducted by Silver (2002) at the Liverpool Regional Paraplegic Centre and included data from the past two decades. Over a period of 20 years there were 626 patients admitted to the Centre of whom only three had rugby injuries. At Stoke Mandeville, Frankel et al (1969) described five rugby cases among 259 traumatic injuries over 17 years. There was a dramatic increase in rugby injuries from 1970 onwards, reaching a peak of 13 players in March 1981. The patients and players consequently held a meeting and in 1984 the injuries of 67 rugby players were described. The mechanism of injury was said to be the head being driven into the ground. These findings were presented at a meeting in Chiltern Hospital in 1983 and the result was a change in the rugby rules. Silver (2002) stated that his personal series of patients had risen to 100 cases by 1994 and that there had been some improvement following the law changes. He stated that at the time of publication there had been 226 papers published on this subject.

Nathan et al (1983) conducted a study on the incidence of cervical spinal cord injuries in schoolboy rugby players during the 1982 season in South Africa and found that the incidence of injury increased with age and that most injuries occurred in the under 19 age group. This finding is in accordance with Horan (1984), McCoy et al (1984), Davidson (1987) and Roux et al (1987).

Silver (1984) stated that in the period from 1952 to 1982, 65 rugby players sustained serious injury to their cervical spines in the United Kingdom. Of these, 22 injuries occurred during the tackle phase of play and the rest during the scrum. Nathan et al (1983) found that 47 % of all injuries involved the tackle and that the tackle and the scrum were the only recorded causes for neck injuries.

Noakes et al (1999) predicts that the frequency of injuries will escalate. The reason stated was that following professionalisation of the sport in 1995 the game reached new heights of physical contact and commitment in tackles. These techniques are copied by schoolboy players with catastrophic injuries as the result of high tackles or tackles that involve vertex impact. He predicts that only when rugby becomes financially accountable for the care of those who are seriously injured will there be any real incentive to reduce injuries. He also states that contrary to popular belief there has not been a reduction in spinal cord injuries following the rule changes in the mid-1980's.

Savage (1995) states that there are no reliable figures for the number of spinal cord injuries sustained during rugby playing and that there is little evidence of a reduction in the number of spinal cord lesions following the rule changes in 1985. This is confirmed by Secin et al (1999) in a study on the incidence of spinal cord injuries in Argentina over a period of 20 years. Noakes and Jakoet (1995) say that there are no reliable data to identify all the spinal cord injuries in the various rugby playing nations. The trend is to only analyse the injuries that caused permanent neurological symptoms and not the players who might have been successfully treated after a serious neck injury. The mechanism of injury that causes cervical spinal cord injuries are the same as for the severe neck injuries without neurological deficit, therefore if spinal cord injuries can be prevented this would also reduce the number of cervical spine injuries.

Garraway and Macleod (1995) studied the epidemiology of rugby football injuries found that rugby injuries were an important source of morbidity in young rugby players. They suggest that the International Rugby Board set up a protocol for studies on the incidence of rugby injuries so that the definition of an injury and the methodology of all future studies would be uniform, so that various studies could be compared.

Kew et al (1991) performed a retrospective study of spinal cord injuries in the Cape Province from 1963 – 1989. They found that the number of spinal cord injuries, because of the scrum collapsing, was dramatically reduced following the rule changes in 1984. However, the number of injuries occurring did not change overall because

the number of spinal cord injuries during the tackle phase of play increased substantially. They suggest that stricter application of the high tackle law alone could reduce the number of serious spinal cord injuries by as much as 30 %. They conclude that the number of serious spinal cord injuries is only the tip of the iceberg of all rugby neck injuries and that there may be as many as 10 severe cervical spine injuries for every cervical spinal cord injury.

5.3 Predisposing Factors for Cervical Spinal Cord Injury

Unlike the rest of the spine, the cervical spinal cord is particularly vulnerable to injury for the following reasons:

- Greater mobility;
- Smaller vertebrae;
- Oblique articular facets;
- Weaker muscle protection;
- Relative mobility of the unsupported skull on the cervical spine.

Torg and Pavlov (1987) postulated that the transient neuropraxia found in USA footballers resulted from a decrease in the anterior-posterior diameter of the spinal canal. Torg and Pavlov (1987) also described a sagittal diameter ratio of the central canal to the vertebral body and found that a ratio of 0.8 or less was indicative of cervical stenosis. Therefore it could be argued that players with a decrease in the diameter of the spinal canal could be at risk for cervical spinal cord injury.

5.4 Mechanism of Injury

The goal of this section is to review the basic science and clinical studies that improves the knowledge and understanding of the mechanism of injury (MOI) and thereby to assist in identifying the possible MOI in cervical spine injury in rugby players. Understanding the MOI is important not only in cases of severe spinal trauma

resulting in neurological deficit of the player, but it may also lead to biomechanical dysfunction found in the cervical spines of schoolboy rugby players.

5.4.1 Failure Models of Ligament versus Bone

The function of a ligament is to transfer loads from bone to bone. When ligaments are subjected to large loads failure may occur either within the ligament or at the bony attachment. Noyes et al (1974) studied failure patterns in the cruxiate ligaments of rhesus monkeys. They compared fast and slow rates of loading and found that bone failed more often at slow speeds and ligament failed at high rates. After immobilisation avulsion of the ligament from the bone was found in all specimens. They concluded that failure takes place at the weakest point. With a fast increase in loading rate the bone strengthens more than the ligament and therefore the ligament will fail first in a normal specimen. In the event of immobilisation the bone weakens more than the ligament and therefore the bone fails first. This should be remembered when the neck is immobilised in a brace after an injury. It is possible that the vertebrae may weaken following periods of immobilisation. Specific studies on human spinal ligaments were not found during the literature search.

5.4.2 Physiologic Strains of Ligaments

During flexion all the ligaments, except the anterior longitudinal ligament, have shown tensile strain. During extension the anterior longitudinal ligament was stretched the most. During right rotation the most strain was measured in the right capsular ligament, and during right lateral bending the left ligamentum flavum underwent the most strain. This can provide information concerning the mechanism of injury. If the right capsular ligament is torn it could be assumed that the mechanism of injury would be right axial rotation. Another interesting finding of this study is the fact that the sagittal and horizontal planes had significant increases in the neutral zones when disc degeneration was present. One may deduct that the degenerated spine may carry a higher risk for increased ligament strains with physiological movements (Panjabi *et al*, 1982).

5.4.3 A Kinematic Approach to Mechanism of Injury

Traditionally the MOIs for cervical spinal cord injury are said to be hyperflexion with or without rotation, hyperextension (Secin *et al*, 1999 and Scher, 1982). The neck of an individual tight row forward is estimated to brace 1 to 1.5 tons (Secin, 1999 and Scher, 1982). Axial loading and spearing (hitting the opponent with the vertex of the head) have been stated by Torg et al (1990) as well as Noakes and Du Plessis (1996:209) as the MOI in tackle football which includes rugby union, rugby league and American Gridiron football.

To build a system for describing the MOI it is necessary to rethink some of the current terms used for example, flexion, extension, rotation, lateral bending and compression injuries. Studies in kinematics and the analysis of forces in the functional spinal unit have shown that these traditional descriptions of injury are no longer adequate to comprehensively describe spinal mechanics and MOI. The traditional motion of flexion can be described as rotation and translation in the sagittal plane. Depending on the force vector, marked different patterns of motion as well as vertebral deformation may be produced. Another example of a MOI is lateral bending where rotation around both the horizontal and vertical axes as well as translation perpendicular to the sagittal plane takes place. Therefore to imply that a MOI involves lateral bending only is an oversimplification. There is a direct and reproducible relationship between the injuries sustained and the loads applied. The loads causing injury to the FSUs are determined by the external loads acting on the body and the specific head – neck – thorax position at the time of the trauma (White & Panjabi, 1990:170-174).

It is crucial to understand the term Instantaneous Axis of Rotation (IAR). The axis dictates the pattern of deformation that occurs in the functional spinal unit (FSU). For example, a force anterior to the IAR will cause flexion and a force applied posterior to the IAR will cause extension. Forces applied to the FSU vary tremendously in speed and magnitude of application. Because of the difference in stiffness and energy-absorbing capabilities of ligaments and bone it may be suggested that the rate of

application of the load determines whether the ligament complex or bone fails first (White & Panjabi, 1990:174).

The understanding of normal kinematics of the various regions of the spine is essential. For example the amount of rotation possible in the horizontal plane is significantly greater in the cervical spine than in the lumbar spine (White & Panjabi, 1990:170).

During the 1975 season 12 American Gridiron football players in Pennsylvania and New Jersey sustained cervical spinal cord injuries. Torg et al (1990) initiated the start of the National Football Head and Neck Injury Registry to ascertain whether this trend was also present in the rest of the USA. An evaluation was made regarding the MOI that caused these cervical spinal cord injuries and it was found that most of these injuries were sustained during a head first collision of the player with an opponent on the ground. Rule changes were implemented to prevent players from blocking or tackling with the head as the first point of contact (Torg *et al*, 1990).

The national Football Head and Neck Injury Registry implicated axial loading as the primary mechanism producing severe cervical spinal cord injuries in football players. The cervical spine is repeatedly exposed to potential injurious energy inputs. Fortunately most of the forces are effectively dissipated by the musculature, intervertebral discs and soft tissues of the cervical spine. When the cervical spine is slightly flexed the normal cervical lordosis is lost and the cervical spine acts as a segmental column. In this situation axial loading of the segmental column will preclude motion and the forces are directly transmitted to the spinal structures. When maximum deformation is reached continued energy input results in angular deformation and buckling with failure of the intervertebral discs and/or bony elements. Essentially the head is stopped, the trunk is still moving and the cervical spine is crushed between the two (Torg *et al*, 1990 and Torg, 1982:139-149).

The most frequent causes for severe cervical spine trauma in rugby players is unilateral and bilateral facet dislocation with accompanying spinal cord trauma. Unilateral facet dislocation is assumed to occur as the result of flexion in the sagittal plane and rotation in the horizontal plane (Noakes & Du Plessis, 1996:209).

During extreme compression, such as the player falling on his head or spearing an opponent with his head, the entire cervical spine may bend or buckle in a manner not consistent with the patterns and range of normal coupled physiological motion. In the event of normal physiological coupled motion inhibited by possible biomechanical dysfunction the result may be even more detrimental. The initial position of the head, neck and thorax are perhaps the most important in determining the mechanical response to any given load. It should be noted that some studies refer to “buckling” as the displacement of the spine from an initial curved position, rather than the buckling of a straight segmented column, as used by Torg above (White & Panjabi, 1990:175-176).

Silver (2002) stated that if the MOI is with the head being on the ground (as happens frequently in rugby) and the cervical spine is rotated, the result will be a bilateral facet dislocation. Roaf (1960) reproduced bilateral dislocation by applying flexion and rotation during a study on cadavers.

According to O’Brien (1996) the MOI to the front row players during scrumming is the direct contact on the C6-T2 spinous processes. He further states that the cervical spine is frequently in flexion when the contact occurs. He suggests that this chronic loading will cause degeneration of the cervical spine.

Scher (1979) said that the MOI during the tackle is due to the trunk remaining static while the head is forced into flexion. Silver (1975) proposed that damage was due to the result of changes in velocity.

Nusholtz et al (1983) suggest that flexion-type injuries from vertical impact of the mildly flexed cervical spine in the mid-sagittal plane are unlikely. However, they found that vertebral body compression and posterior ligamentous disruption were readily produced in axially rotated or laterally flexed spines. This study therefore emphasises the importance of not loading the midsagittal plane. Roaf (1960) could only produce pure ligamentous injuries with flexion and extension movements. He further states that there is no such thing as a hyperflexion injury because the normal range of motion for flexion is chin to chest. He further said that vertebral body crush

occurred prior to posterior ligament tear. He further noted that the FSU were very vulnerable to rotation and noted that the discs were subject to injury because of the horizontal shear forces produced by rotation. Therefore if there is extensive ligamentous disruption clinically, the possibility of a rotary MOI around the y-axis should be considered.

In a study by Gosch et al (1972) on monkeys the investigators found that in addition to flexion it was necessary to induce axial rotation to produce dislocation. This is in keeping with the findings by Roaf (1960) and Bauze and Adran (1978) on cadaver specimens. They also indicated that the muscle tone at the moment of impact has a profound effect on the threshold of forces required to cause spinal cord damage. Muscle tone was required to solicit cord damage, therefore the more relaxed the individual is at the moment of physical trauma the smaller the chance of spinal cord damage. This assumption holds true unless the magnitude of the forces is low enough to be checked by the intrinsic splinting power of the subject's muscles.

Nightingale et al (1996) performed a study to investigate cervical spine trauma due to head impact. They used unembalmed human heads with intact spines. The muscles were removed and all ligaments were left intact. The specimens were fixed in an anatomically neutral position and then dropped from various heights. These experiments demonstrated that the head inertia can constrain cervical spine motion and produce injury in the absence of a pocketing impact surface. As a consequence of head inertia, the injuries occurred prior to any significant head motion. The more dramatic head motions, often associated with cervical spine injuries, did not occur until after the injury. The type of injury was dependent on the cervical spine deformation that occurred shortly after head impact. The head motion following injury depends on the contact surface and the orientation of the cervical spine. They concluded that head motion cannot be used to predict or classify impact injuries. Dynamic structural buckling modes of the cervical spine were observed. The buckling modes may be transient and are not directly associated with injury. However, they alter the cervical spine kinematics and may therefore influence the types of injuries which are produced.

Authors (Noakes & Du Plessis, 1996:121; Bogduk & Yoganandan, 2001) suggested that some of the mechanisms of injury during rugby could be described as whiplash type injuries. Therefore the literature on the analysis of whiplash injuries is also included in this section.

Bogduk and Yoganandan (2001) found that during a rear collision simulation the cervical spine as a whole did not exceed physiological ranges of motion at any stage. However, lower cervical spine segments consistently exceeded physiological limits of posterior rotation. As the cervical spine was compressed, the lower cervical vertebrae underwent rotation about an abnormally located axis. The anterior elements separated while the facet joints impacted. At high speeds the intervertebral discs may tear and the facet joints may be bruised or fractured. The force producing the movement was an upward thrust. No shear force was exerted and no translation occurred. Muscles were recruited relatively late during the whiplash event after approximately 100 to 125 ms, but it could take a further 60 ms to develop tension. In the unbraced individual the delay may be 200 to 250 milliseconds. Because of their passive stiffness the muscles may have influenced the excursion of the head that occurred late in the whiplash event. By the time the muscles were activated the compression and abnormal intersegmental movements, that seem critical to injury, had already occurred.

Neck muscle onset times during whiplash loading have been studied by a number of authors but the amplitude of muscle response has been largely overlooked. In a study by Brault et al (2000) the cervical spine muscles were tested in bumper to bumper collisions between a rolling bullet vehicle and a stationary target vehicle. Each subject was exposed to two impacts, one at 4 km/h and one at 8 km/h. The order of impact was randomized and separated by at least seven symptom free days. The data indicated that there are at least two distinct phases to the muscle response during whiplash loading. The first phase of muscle contraction consists of flexor and extensor co-contraction and occurs during an interval that corresponds roughly with the dynamic retraction of the head relative to the torso. From an injury perspective this co-contraction during the retraction phase may be important, since during this phase the largest acceleration between the head and the cervico-thoracic junction occurs. This may be a reflexive attempt to stiffen the head / neck complex in order to

minimise relative motion. Unfortunately the primary vertical line of action of most neck muscles is not optimal to prevent the predominantly horizontal movement between the head and the neck observed in the tests conducted by these authors. This poor line of action may partially explain the continued increase in retraction well after the SCM muscle reached its peak length.

After maximum contraction was reached, the sternocleidomastoid (SCM) muscle became inactive, while the cervical paraspinal (PARA) muscles remained active, or at greater speeds, increased their contraction level. This suggests that the phase two response is also reflexive. In conclusion, the muscles contract rapidly in response to impact and the potential of muscle injury due to lengthening contractions exists (Brault *et al*, 2000).

Hodgson and Thomas (1980) first described dynamic cervical buckling as a “ducking” deformation. The buckling mechanism, which produces flexion injuries during compressive impacts, is widely accepted in clinical literature as the cause of “hyperflexion” injury in headfirst football tackling techniques. Impact experiments have also produced transient second-order buckling modes prior to the first-order mode, raising the possibility of additional injury mechanism. The complex deformation resulting from higher-order buckling may explain the various injuries associated with axial impact loading (Nightingale *et al*, 2000).

The purpose of a study by Nightingale *et al* (2002) was to examine the relative importance of mass, mass moment of inertia, stiffness and loading rate on the expression of buckling modes in the ligamentous cervical spine. These authors hypothesized that during compressive impact the inertial properties of the cervical vertebral bodies play an important role in determining the buckling behaviour. The hypothesis was tested using a segmented beam column model. Their results indicate that second-order buckling modes are the consequence of inertial effects. For small values of mass, the inertia of the column segments is small, relative to the elastic loads exerted by the joints. Therefore the column deforms in a way which minimises the total elastic energy in the rotational springs. As the mass of the segments increases the inertial forces of the segments become more significant. At higher rates the mass characteristics dominate the response and the column deforms in more complex ways

to minimise its total kinetic energy. Because of the inertial effects, higher loading rates increased the likelihood and the duration of higher-order buckling modes.

When the cervical spine is in a neutral position with the normal cervical lordosis it can withstand the highest amount of axial compressive forces before failing. The cervical spine acts as a segmented column when the cervical lordosis is lost. Loss of cervical lordosis occurred such as with approximately 30 degrees of flexion. The orientation and alignments of the various cervical spine structures in relation to the head and thorax during the moment of impact can affect the resulting injury (Nightingale *et al*, 2000).

The mechanisms responsible for injury in any sport and rugby in particular are many and varied. A classification system that could be used to identify basic factors that could describe the mechanism of injury is the following (Whiting & Zernicke, 1998:114-121):

- Contact or impact
- Dynamic overload
- Overuse
- Structural vulnerability
- Inflexibility
- Muscle imbalance
- Rapid growth

It can be seen that any one or more of the above could be a predisposing factor for cervical spine injury in the schoolboy rugby player and the following truisms are stated:

- There is definitely a lot of contact and impact in the game of rugby
- During the scrum and high tackle there is definitely a high possibility of dynamic overload of the cervical spine
- During training and match play, there is repeated scrumming and tackling and the cervical spine could definitely be overused
- The cervical spine is made for mobility and not stability in contrast to the lumbar spine which is designed for stability

- Generally cervical spine exercises focus on the posterior cervical muscles and upper fibres of trapezius and the emphasis on the anterior cervical spine muscles as well as scapula and thus lower fibres of trapezius are neglected. This could cause a muscle imbalance.
- The age group of players between 15 and 18 years of age have rapid growth spurts which could predispose them to injury.

In summary these studies demonstrated that the initial head-neck-thorax position and loading conditions dictate the cervical spine's response to impact. There appears to be three patterns of response: bending of the curved spine under axial load; buckling of the straightened spine under axial load and the deflection of the spine out of the load path. Varying the initial position altered the type of response, maximum load at failure and the extent of injury. In addition non-midsagittal loads will lower the injury threshold.

5.5 Prevention of Cervical Spine Injuries

Taylor and Coolican (1988) looked at preventative programmes and rule changes to make rugby safer. They reasoned that because there were very few cervical spinal cord injuries in players younger than 14 years of age one could assume that the very flexible immature spine of the adolescent provides a measure of protection against injury. These researchers also stated that no acceptable evidence exists to prove that stronger neck muscles protect against neck injuries. They say that a powerful neck and torso contributes to the forces in rugby union with power scrumming forming part of the game. They state that the mechanism of injury in American football has been studied in great detail and that axial loading was pinpointed as the cause of injury.

Noakes et al (1999), in an article on an apparent reduction in the incidence and severity of spinal cord injuries in schoolboy rugby players in the Western Cape since 1990, stated that the number of cervical spinal cord injuries in schoolboy rugby players during the scrumming phase of play were the same as the historic proportion at approximately 19 %. They concluded that this was true because of the laws not being enforced or that the mechanism of injury was not sufficiently addressed. They

also said that greater emphasis should be placed on the tackling and ruck and maul phases of play, since 81 % of injuries occurred during these phases of play. The apparent reduction in injuries was therefore not because of the rule changes, but probably because of stricter enforcement of the dangerous play law.

Although neck muscle exercises have been suggested by many authors the literature indicates no objective and quantitative measurements recommended for strength requirements in rugby players. Scher (1981) suggested proper conditioning of the neck muscles for reducing the number of cervical spine injuries. Noakes et al (1999) also suggested that players who are not trained and conditioned to play in the scrum should not play in any position in the rugby scrum.

5.6 Summary

The literature review chapters focused on evidence based research found in the literature to motivate the current study. This chapter looked at cervical spinal cord injuries in rugby players in terms of incidence, mechanism of injury as well as prevention and the role of the physiotherapist and educator in this. The concepts explained in this chapter were utilised to develop the protocol for this study and will be detailed in the next empirical study chapter.

Chapter 6

Empirical Study

This chapter will include the entire empirical study process followed and will include the results of the pilot study, the study design, inclusion and exclusions criteria, ethical considerations, as well as the results of the manual physiotherapy evaluation technique validation. A detailed discussion of all the interventions performed by the various subjects will subsequently be described followed by the statistical analyses used for analysing the data.

6.1 The Importance of Evidence Based Practice

The evidence based practice drive has had a significant positive impact on the physiotherapy profession (Jones, 2004). The dominant research paradigm driving evidence based practice is without a doubt the quantitative paradigm and the dominant research strategy is the randomised control trial (RCT) used in investigating the effectiveness of therapeutic interventions. Numerous variables contribute to our health, either as genuine risk factors to the development of a health condition or as a factor in how we cope with injury or illness (WHO, 2001). The evaluation of physical function and impairment alone cannot provide the health care professional with a complete health profile. Subjective views of health status, quality of life and the patient's perspective on their pain, disability and future prospects are increasingly measured in quantitative studies where questionnaires are being used. The current study has therefore considered aiming at changing the way a schoolboy rugby player view the future prospects of the health of his cervical spine as well as providing him with an effective programme to reduce the risk of injury to his cervical spine.

The process indicating the steps of the research conducted starting with school selection to commencement of the actual procedure is provided in a flowchart (Figure 6.1). The flow of the study was influenced strongly by the results of the pilot study performed prior to the start of the main study.

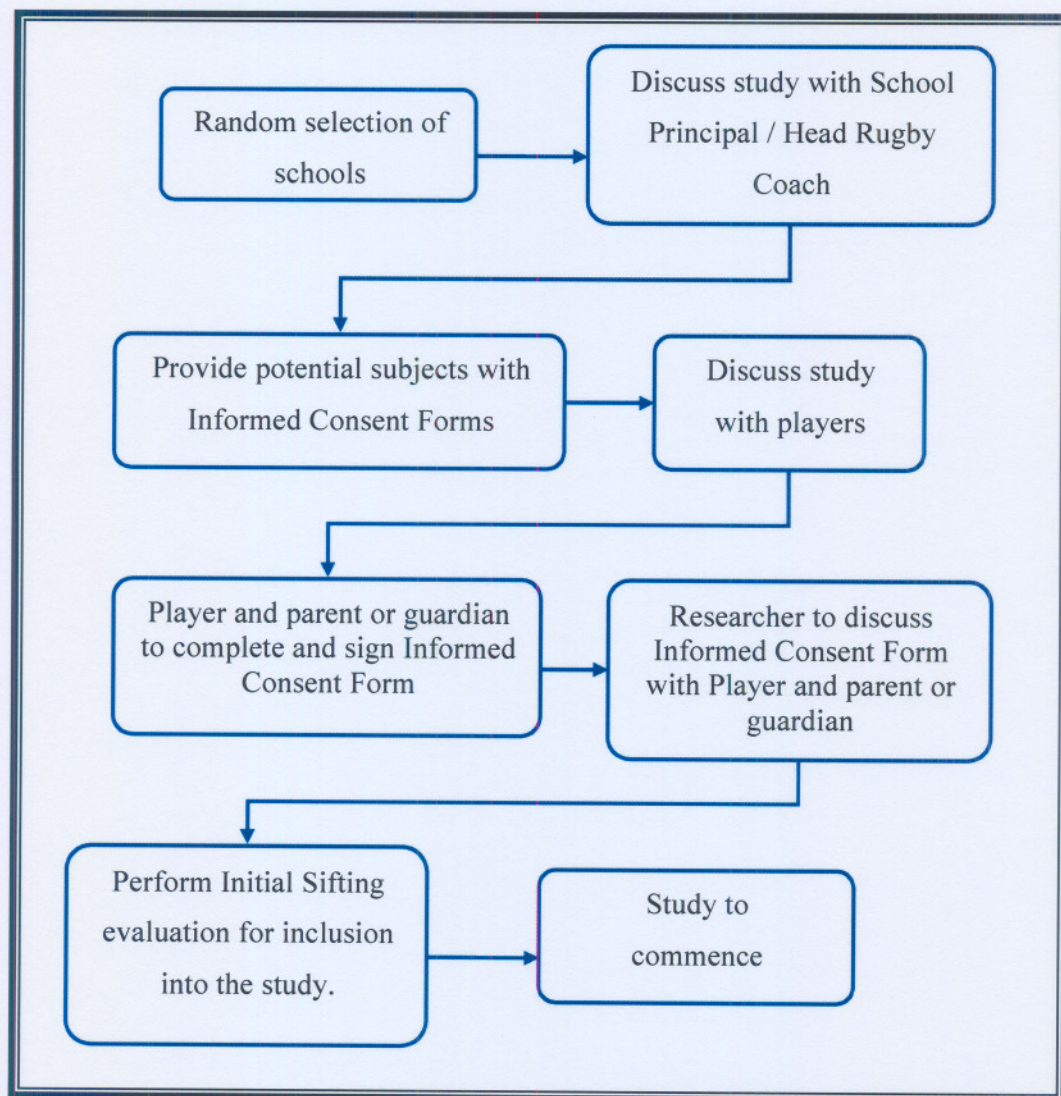


Figure 6.1: Flowchart to illustrate the selection sample population.

6.2 Pilot study

6.2.1 Aim

The aim of the pilot study was to screen schoolboy rugby players from the proposed study population for cervical spine biomechanical dysfunction and to determine the

timeframe for correction of cervical spine biomechanical dysfunction using the therapeutic exercise programme for the correction of biomechanical dysfunction and the applied physiotherapy treatment technique. As a clinician the researcher usually treats cervical dysfunction with hands on manual physiotherapy techniques. A control group also performed the corrective exercises and was evaluated to determine whether any cervical biomechanical dysfunction developed as the result of the corrective exercises.

6.2.2 Method

A population of 12 schoolboy rugby players were randomly selected for the pilot study. Three groups of 4 players each were included. Players in the manual physiotherapy treatment group (Group A) and players in the group who performed the therapeutic exercise programme for the correction of biomechanical dysfunction (Group B) had biomechanical dysfunction of their cervical spines, defined as one or more motion segment / s with abnormal movement patterns. The control group (Group C) had no dysfunction of their cervical spines.

Only the physiotherapy screening evaluation technique was used with no x-ray verification since this would be too costly for a pilot study and the aim of the pilot study was to determine when correction of the dysfunction occurred.

All the players were seen three times a week for a period of two weeks where the Group A was treated and Groups B and C performed the therapeutic exercise programme. Each player was evaluated before and after each session.

6.2.3 Results

It was found that biomechanical function was restored for all the players who received the manual physiotherapist treatment technique (Group A) within one or two treatment sessions. They remained so for the duration of the two weeks (Figure 6.2).

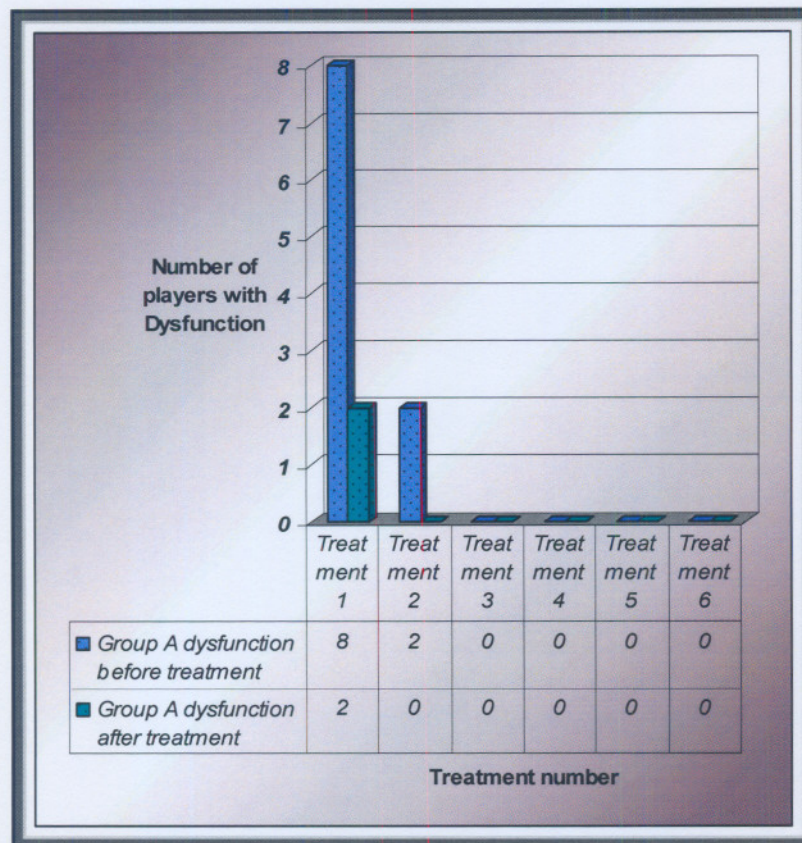


Figure 6.2: Results of the pilot study for Group A.

Biomechanical function was also restored for the players of Group B, players who performed the therapeutic exercise programme for the correction of biomechanical dysfunction. This correction was achieved following two or three exercise sessions performed during the first week and remained so for the duration of the second week (Figure 6.3). The players who performed the regime without having cervical dysfunction (Group C) did not develop any dysfunction during the two weeks of the pilot study.

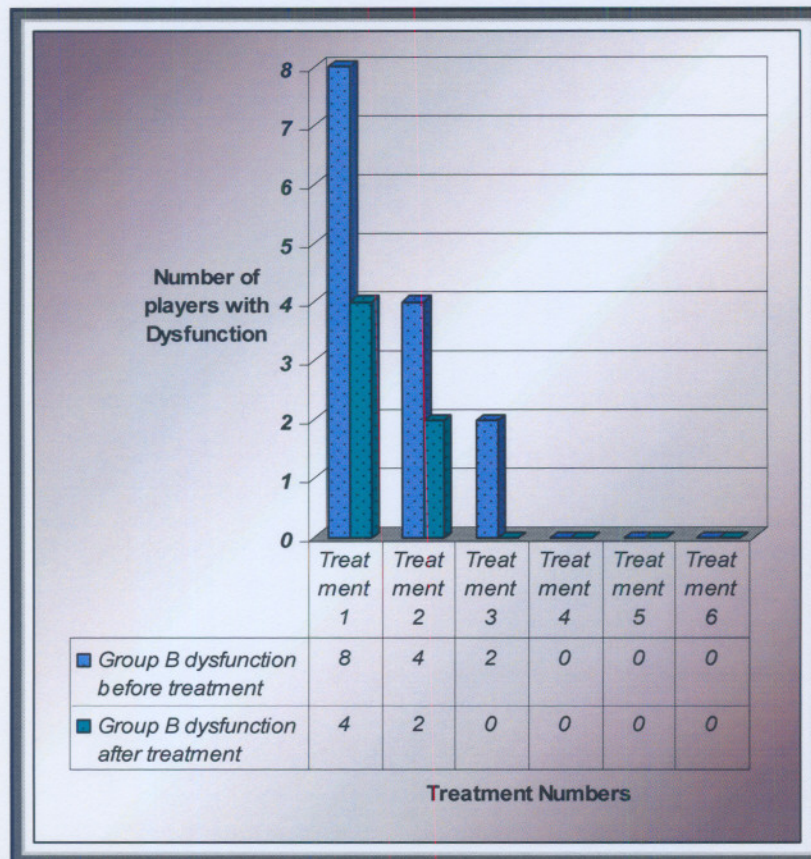


Figure 6.3: Results of the pilot study for Group B.

6.2.4 Conclusion for the thesis study

It was therefore decided to perform the therapeutic exercise programme for the correction of biomechanical dysfunction three times per week for the initial three weeks and then to start with the neck rehabilitation programme to stabilise the cervical spine in a non-dysfunctional position. The players will be re-evaluated at regular intervals during the course of the study as described in the protocol. The group receiving physiotherapy treatment will start with the strengthening programme as soon as no dysfunction is found for two consecutive treatment sessions. This is expected after the first week of treatment.

A problem was encountered by the researcher not expected at the start of the pilot study. The players were randomly selected to the various groups, a number of the

players in the group who perform the therapeutic exercise programme complained because they wanted to be included in the group who received physiotherapy. It was therefore decided to only randomise the schools to be included in the study and to perform only one type of intervention at each of the selected schools. This will also facilitate the inclusion of the various exercise programmes into the regular training sessions.

6.3 Study Design

The study design used will be a four group experimental design with three pre-test, post-test groups and a control group. The researcher attempted to follow the randomised control trial study design with the following exceptions because of difficulties experienced during the pilot study. During the pilot study the researcher received feedback from the subjects that they perceived one form of treatment superior to the other and all of them wanted to be included in the group who received physiotherapy. For the main study it was therefore decided that one form of intervention should be isolated within one school. The schools selected for the study were however randomised and the players selected from each school were randomised.

E ₁	Y ₁	X ₁	Y ₂
E ₂	Y ₁	X ₂	Y ₂
E ₃	Y ₀	X ₂	Y ₂
C	Y ₁	--	Y ₂

6.3.1 Blinding

It was not possible to blind the subjects to the treatment that they received, although emphasis was placed on blinding them from any pre-randomization expectation biases to the efficacy of the different treatments. Although these factors are considered to threaten the methodological quality of a randomized clinical trial, it is common to face such limitations in studies designed to evaluate exercise or physical therapies.

6.4 Study Population

The study population consisted of schoolboy rugby players between 15 and 18 years of age in the Gauteng Province of South Africa. The sample was a non-probability sample with subjects being selected from rugby playing high schools in the selected region, willing to participate in the study. The schoolboy rugby players were selected from randomly selected schools from all the state owned high schools, who participated in the game of rugby, in the metropolitan area of Ekurhuleni, Gauteng, South Africa. Initially three schools were selected in a randomised manner.

Considering a 95 % confidence level and a 40% improvement in the number of players with cervical biomechanical dysfunction, the sample size of each group was suggested to be 25 subjects for results to be considered statistically significant.

6.5 Study Sample

The sample of subjects did not come from a random sample of South African schoolboy rugby players, but was in general terms a reasonably representative subset of South African schoolboy rugby players. The subjects for this study were recruited on a voluntary basis from the selected schools and therefore represent a group of self-motivated players who understood the importance of taking responsibility for their own well being.

The researcher explained the study to 200 potentially eligible rugby players representing the selected schools and handed informed consent forms out to them. These players were selected into groups of 25 players for the subsection of the sample with specific inclusion and exclusion criteria for each group (see below).

Group 1

Group 1 (E_1) included subjects with cervical biomechanical dysfunction who received manual physiotherapy treatment, performed by a skilled physiotherapist (X_1), to restore cervical biomechanical dysfunction found on evaluation. These subjects were selected from the first randomly selected school.

Group 2

Group 2 (E_2) included subjects with cervical biomechanical dysfunction who were provided with a therapeutic exercise programme for the correction of biomechanical dysfunction, based on the manual physiotherapy treatment technique (X_2), to restore their cervical biomechanical dysfunction. These subjects were selected from the second randomly selected school.

Group 3

Group 3 (E_3) included subjects without any cervical biomechanical dysfunction who were provided with the same therapeutic exercise programme for the correction of biomechanical dysfunction (X_2), to test for possible adverse effects of the programme. These subjects were selected from the second randomly selected school.

Group 4

C was the control group and this group included subjects with or without cervical biomechanical dysfunction. These players received no intervention and were selected from the third randomly selected school.

6.5.1 Inclusion Criteria

6.5.1.1 Inclusion Criterion for all Participating Subjects

All the participating subjects had to be schoolboy rugby players between the ages of 15 and 18 years.

6.5.1.2 Specific Inclusion Criterion for Groups 1 and 2

Cervical biomechanical dysfunction of one or more motion segments of the cervical spine.

6.5.1.3 Specific Inclusion Criterion for Group 3

No biomechanical dysfunction of the cervical spine.

6.5.2. Exclusion criteria:

- Any player suffering from any systemic disease that may have had a detrimental influence on the structural biomechanics of the cervical spine at the time of selection.
- Any subject suffering from a congenital neuromusculoskeletal dysfunction that could influence the structural biomechanics of the cervical spine.
- Players falling outside the bracket of 15 to 18 years of age.
- Players with an episode of neck pain or injury during a period of one year prior to the initial x-ray investigation. In this study the definition of injury as used by Roux *et al* (1987) in their study of South African schoolboy rugby players was used. They defined injury as an injury that prevents a player from playing rugby for seven or more days or that requires medical or surgical treatment after a sustained injury.
- Players who had received medical treatment including physiotherapy, medicine or surgery for neck pain not falling within the definition of an injury as stated above, within a three month window period preceding the initial x-ray investigation.
- Any player who had not participated in playing rugby for at least one season prior to the time of subject selection.
- Any player whose parent or guardian had not consented to the subject's participation in the study.

6.6 Ethical Considerations

This research study was approved by the Ethics committee of the Faculty of Education, North West University.

The researcher approached the principals and / or head coaches of the selected schools and a personal visit was arranged to explain what the study entailed. All the principals and / or head coaches of the selected schools agreed that learners from their schools could participate in the study.

The researcher then visited these schools and discussed the study with the potential schoolboy rugby players, who fell within the eligible age group with the necessary inclusion criteria, and motivated them to participate in the study. All interested players received an informed consent form and they were required to peruse the contents and then give it to their parents or guardians for review (Appendix A). Parents / guardians who agreed to the rugby player participating in the study were required to sign the informed consent form. The researcher included her contact details and the parents could phone to ask any questions regarding the study. There were no costs for the subjects. The informed consent form was based on the informed consent principles of the Declaration of Helsinki, 1964 and amended by the 41st World Medical Assembly, Hong Kong September 1989 and in South Africa October 1996.

6.7 Measurement Tools and Instruments

- Portable examination plinth.
- Standard domestic measuring tape.
- Questionnaire handed to potential subjects (see Appendix B)
- Planned evaluation form to record data (see Appendix D)
- X-ray machine
- Computer software program (Centricity Radiology RA 600, GE Medical Systems, 2002)

- X-ray scanner (Siemens)
- Digital camera (HP Photosmart R707)
- Standard tennis balls
- Green Theraband one meter lengths
- Silver Surgical Tubing one meter lengths
- Calibrated bathroom scale

6.8 Procedures

Each player who responded and complied with the inclusion criteria and whose informed consent form was signed was included in the initial sample of players with possible inclusion in the study. The players also received a confidential initial questionnaire (Appendix B), which enquired about medical history, previous pain, injury or surgery as well as any possible systemic condition that would exclude participation in the study. The subjects were also asked questions concerning the neck exercise they performed prior to the start of the study. This enabled the researcher to obtain basic demographic information and to determine the suitability of including these volunteers in the study.

After completion of the questionnaire the researcher determined whether any of the exclusion criteria were applicable to any of the players and then continued with the initial sifting process.

6.8.1 Initial sifting

At each of the randomly selected schools the researcher performed a biomechanical evaluation of the schoolboy rugby players fitting the inclusion criteria. The biomechanical function for each player was noted according to the proposed manual physiotherapy evaluation technique (Appendix C). The players were then allocated to the various groups with 25 players in each group, matching age and playing positions for each group.

Following the initial sifting into groups all the players who complied with the inclusion criteria were then taken for their first set of x-rays. Following these x-rays the manual physiotherapy evaluation technique was subsequently validated.

6.8.2 Validation of the Manual Physiotherapy Evaluation Technique for Motion Segment Analysis

In order to determine the effectiveness of any intervention for the correction of biomechanical dysfunction in the cervical spines of schoolboy rugby players it is necessary to evaluate the motion segments of the cervical spine for any possible dysfunction. A reliable, valid evaluation technique is therefore of utmost importance. The following section will provide the results of the validity and reliability of the physiotherapy evaluation technique used for this study and described in the previous chapter (Chapter 4:82).

As stated in chapter 1 normal biomechanics of a motion segment could be described as the position where the motion segment is held in a physiological state of rest. This would imply the least amount of intra-joint pressure, least amount of connective tissue tension and the least amount of electromyographic (EMG) muscle activity (Chapter 1:4). Considering this, dysfunction of a motion segment could therefore be described as any position where the motion segment is not in a physiological state of rest. With dysfunction normal movement of the segment will be affected with restriction to one or more directions of the movement.

According to Rocabado (1999) the motion segment movement pattern of cervical rotation with lateral flexion to the opposite side (Chapter 4:82) is an indication of the flexion movement potential of the motion segment. He stated that in the event of restriction of this movement pattern one can expect restriction of the flexion movement for that particular motion segment. If restriction of the movement of rotation and lateral flexion to the same side is found, this would indicate restriction of extension movement for that specific motion segment. This evaluation technique has

to date not been validated through research and therefore one of the aims of the study is to test the validity of this evaluation technique.

The cervical spine biomechanical dysfunction mostly found in the cervical spines of the schoolboy rugby players was restriction of the movement pattern of rotation and lateral flexion restriction to the opposite side (Steyn, 2002). As theorised by Rocabado, this would be seen as a restriction of the flexion movement of the motion segment on x-ray. Theoretically it could therefore be expected that the x-ray measurement of the flexion angle of players evaluated as having cervical spine biomechanical dysfunction should be less than the flexion angle found in the players without biomechanical dysfunction. The flexion angle of the motion segment was measured as the angle between the midplanes of the vertebrae forming the motion segment when the cervical spine performs a flexion movement (Chapter 4:80).

In determining the validity of the physiotherapy evaluation technique the x-ray measurements for the flexion angle, the extension angle as well as the angle of rotation of the tested motion segments were compared to the physiotherapy biomechanical dysfunction found by the examiner. All the players who were found to have unilateral or bilateral restriction to the movement pattern of rotation and lateral flexion to the opposite side were grouped together and compared to the group of players where the researcher found no biomechanical dysfunction. The mean flexion and extension angles as well as the mean angles of rotation were subsequently compared.

The effect sizes (d-values) for the results of this comparison are given in Figure 6.4. The C5/C6 level were statistically highly significant with an effect size for the mean flexion angle of $d = 1.085$. This would suggest that the theory of the movement pattern of rotation with opposite lateral flexion restriction is indeed analogous with a restricted flexion angle x-ray measurement. This provides validity to the theory suggested by Rocabado for the C5/C6 motion segment. The other motion segments measured had small to moderate statistically significant results, with the C3/C4 motion segment testing the poorest correlation. The measurements for extension angle indicated small significant results. The C5/C6 motion segments' angle of rotation showed a high statistically significant result with an effect size of $d = 0.810$.

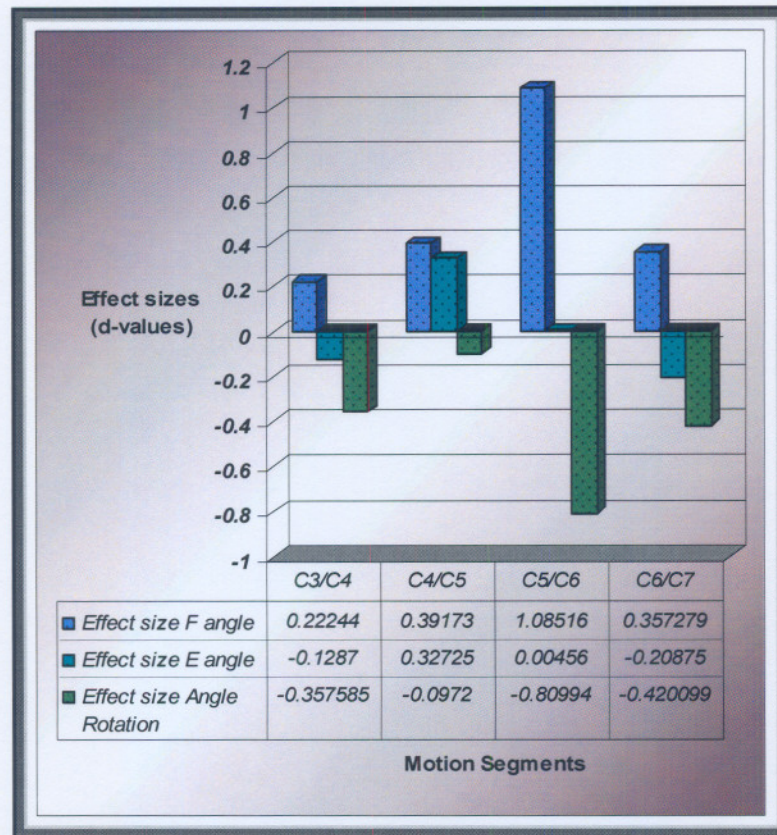


Figure 6.4: The effect sizes (d-values) for the results testing the validity of the Physiotherapy Evaluation Technique.

As stated before (Chapter 4:82) various authors concluded that physiotherapists have fairly poor reproducibility and good repeatability in locating C5, T6 and L5 spinous processes by palpation. This finding, for the cervical spine, was confirmed in this study. The reliability for evaluation the C5/C6 motion segment was found to be statistically more significant than any other of the motion segments evaluated (Figure 6.4).

The Rocabado (1999) theory that restriction of the movement pattern of rotation and lateral flexion to the opposite side indicates a restriction of the motion segment into the flexion movement was confirmed by the results. The mean flexion angle of the subjects with biomechanical dysfunction of the C5/C6 motion segment, according to

the physiotherapy evaluation technique, was -1.855° compared to the mean flexion angle of the subjects evaluated as not having biomechanical dysfunction of -6.968° .

It could therefore be concluded that this evaluation technique is valid in determining biomechanical dysfunction of the cervical spine, but not highly reliable in determining the exact motion segment level of dysfunction. For the physiotherapy profession this result is were important since this evaluation technique could be used to evaluate the cervical spine for possible biomechanical dysfunction in a multitude of conditions that could contribute to pain and dysfunction, such as whiplash injury, chronic neck pain etc.

Having found the manual physiotherapy evaluation technique valid in determining cervical spine biomechanical dysfunction it would imply that the initial sifting performed by the examiner to determine the sorting of the players into the various groups were reasonably correct.

6.8.3 Detailed Physiotherapy Assessment

The detailed assessment was then performed for all the subjects, by the researcher in a room, which ensured the necessary privacy. The player, his parent or guardian could have requested the presence of any other person of his or her choice to be present during the evaluation process. For the details of the subjective and objective examination see evaluation form (Appendix D). The researcher initiated the assessment by conducting the subjective and initial objective part of the evaluation, in the order printed on the evaluation form. Researcher blinding was not possible.

6.8.3.1 Subjective Evaluation

An interview was conducted by the researcher with the subject during which time his medical history was discussed and recorded. The subjective assessment was performed according to the guidelines as described by Magee (1997:103). The researcher enquired about any current symptoms, including any neurological signs and symptoms as well as the area and intensity of any present pain. This was

necessary to ensure that it would not be necessary to exclude any subject due to any existing exclusion criteria. The researcher also enquired about the subject's playing position as one of the sub-aims was to investigate biomechanical metrics of the cervical spine dysfunction in forwards and backs.

6.8.3.2 Age and Anthropometric Measurements

The age of the player was determined on the day of the evaluation according to his identity document number, as provided by the player. Body mass was measured, using an electronic scale. Muscle strength is proportional to the cross-sectional diameter of the muscle fibres. The size of the muscle should increase in cross-sectional diameter with resistance training (Kraemer *et al*, 1998). It was therefore decided to include measurement of the diameter of the neck in the players to measure if the circumference of their necks increased over the period of the rehabilitation programme. The cervical circumference of the rugby player was measured using a piece of string around the neck of the rugby player in the mid cervical region with the anterior part of the string running inferior to the Adam's apple (laryngeal prominence). The string was then measured on a standard measuring tape.

6.8.3.3 Ligament Stability Upper Cervical Spine

Stability of the cervical transverse ligament was assessed in the following manner: the therapist places one hand over the subject's forehead while the thumb of the other hand is placed over the spinous process of C₂ to stabilise it. The subject is asked to do flexion of the head, while the examiner presses posteriorly (Magee, 1997:131 and Rocabado, 1999).

The stability of the alar ligaments was assessed as described by Kaltenborn (1993:226) and Rocabado (1999). The therapist stands at the right side of the subject while the subject sits on a low chair. The palpating finger of the left hand is placed on the lateral side of the spinous processes of C₂ to C₃. The right hand of the

therapist is placed on top of the subject's head. The therapist sidebends the subject's head and an immediate rotation of C₂ to the opposite side should be palpated.

The functional space between the occiput and C₂ was palpated. The position of C₁ and C₂ was assessed. (Kaltenborn, 1993:225-226 and Rocabado, 1998). The therapist stands on the left side of the subject and the therapist tests left rotation of the atlas in relation to the axis.

6.8.3.4 Motion segment analysis

The motion segments of C₂ – C₇ were evaluated using the manual physiotherapy technique validated earlier (Chapter 6:169). The position in which the segment was held was determined. The therapist places the palpating finger of the left hand on the motion segment to be assessed. The remaining part of the hand is placed to stabilise caudal to the segment. With the cervical spine positioned in the neutral position the therapist rotates the head to the left and in this rotated position the therapist performed lateral bending first to the left and then to the right, noting any restrictions to the movement. This was compared to the other side. This physiotherapeutic evaluation technique has been proven valid (Chapter 6:169). Any restriction to the lateral bending part of the movement pattern was considered as an indication of biomechanical dysfunction for that particular motion segment. A qualification or quantification of the degree of the restriction is not required for this particular evaluation technique. Restriction of the lateral bending component to the ipsilateral side was considered as an extension restriction and restriction of the lateral bending component to the contralateral side was considered as a flexion restriction (Rocabado, 1999). This was confirmed by the findings during the validation process (Chapter 6:170).

6.8.3.5 Neurodynamic Testing

The neurodynamics of the upper limb was assessed by applying the upper limb neurodynamic base test (Magee, 1997:123-124). See Figure 6.5.



Figure 6.5: Upper limb neurodynamic test (ULTT1). (Magee, 1997:124).

6.8.3.6 Posture

The researcher used a digital camera to photograph the subject with an anterior, posterior and lateral view. The photos were superimposed on a grid and the posture of the subjects evaluated as described by Kendall et al (1993:69-119) and Magee (1997:705): The following Figures 6.6 to 6.8 illustrate the various posture types evaluated for the schoolboy rugby players. See Figures 6.6 to 6.8.

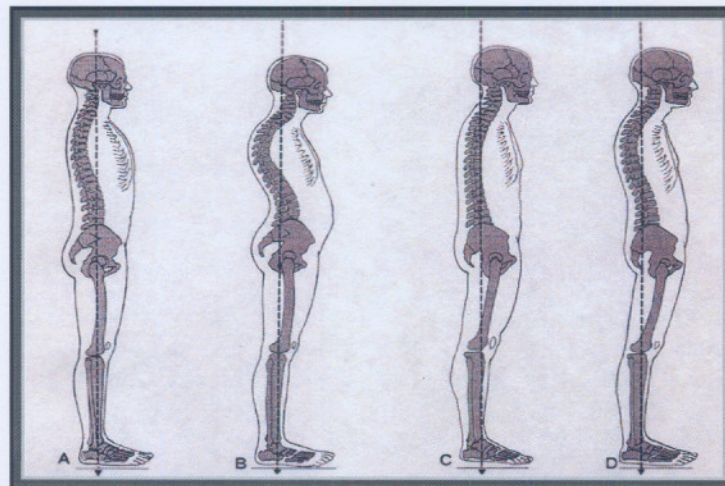


Figure 6.6: Ideal (A), Kyphosis-lordosis (B), Flat back (C) and sway back postures. (From Kendall *et al*, 1993:76).

Forward Head Posture

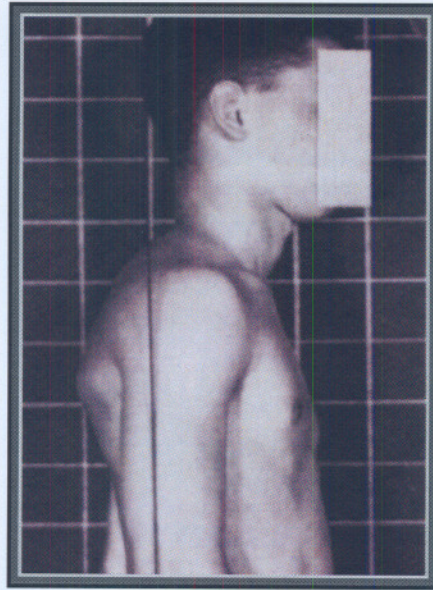


Figure 6.7: Forward head posture. (From Kendall *et al*, 1993:91)

Scoliosis

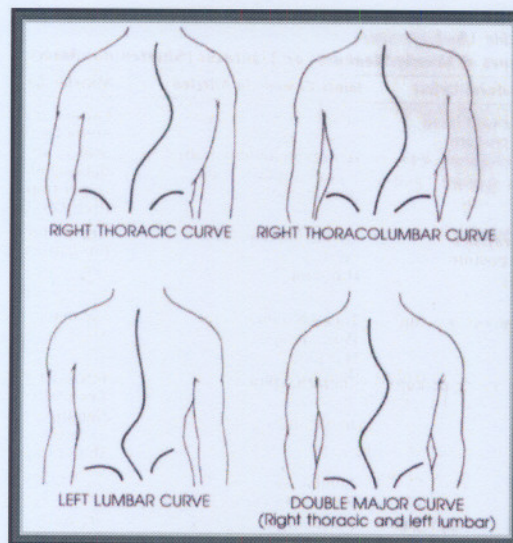


Figure 6.8: Examples of scoliosis curve patterns. (From Magee, 1997:705).

6.8.4 Radiography

Transportation to the radiology department (Burger and Partners Inc) were organised for all the selected schoolboy rugby players. One of two radiographers performed the x-ray examinations of the cervical spines of the all the subjects.

6.8.4.1 Technique for X-ray Examination

Subjects stood in an upright position with the left side of their bodies closest to the x-ray film. The subjects were informed not to perform flexion and extension in the thoracic spine and to hold their shoulders as low as possible in order to visualise the cervico-thoracic junction. The distance between the x-ray tube and the film was 150 cm. The radiographer explained the procedure to the subject and observed for a proper flexion and extension movement. Flexion and extension was performed to the end of the subject's available range of motion and the x-ray was then taken in this position (Dvorak *et al*, 1991).

6.8.4.2 Measurements Performed

The x-ray measurements as discussed in the literature review (Chapter 4:77) were performed. The entire cervical spine had to be included on the lateral view. Mobility studies are lateral views performed in maximum voluntary flexion and extension. Traditionally these views were performed to locate and document ligamentous stability and disruption (Torg, 1982:130). Additionally for the current study these views will help in determining the intersegmental motion of the cervical spine. In flexion there is an increase in the intraspinous distances, widening of the posterior aspect of the interfacetal joints and intervertebral disc spaces, and narrowing of the anterior aspect of the intervertebral disc spaces. The vertebrae may normally slide anteriorly up to 3mm on the subjacent vertebrae. These changes should be gradual and consistent throughout the cervical spine. All these changes are reversed in extension (Chapter 4:75).

Beginning with the extension view, four lines were drawn tangential to the four sides of the vertebral body of each vertebra. Their intersection provides four corner points. This was repeated for the flexion view (Dvorak *et al*, 1991). The midplane was then constructed for each vertebra by determining the midpoint between corners 1 and 3 and 2 and 4 respectively (Figure 6.9, same as Figure 4.4). The angle was counted positive if the wedge opens anteriorly. The example illustrated in Figure 6.9 therefore represents the extension angle for this particular motion segment (Frobin *et al*, 2002). The angles of rotation were calculated by subtracting the flexion angle (in degrees) from the extension angle (in degrees) as explained previously (Chapter 4:80). The translation measurement for each motion segment was then measured. Perpendiculars were constructed from the centre points of adjacent vertebrae onto the bisectrix between the midplanes (Figure 6.9 same as Figure 4.4). Posteroanterior displacement is defined as the distance between those points where the perpendiculars intersect the bisectrix. Thus, displacement (and consequently translational motion) is measured along a direction coinciding in good approximation with the midplane of the disc (Chapter 4:81).

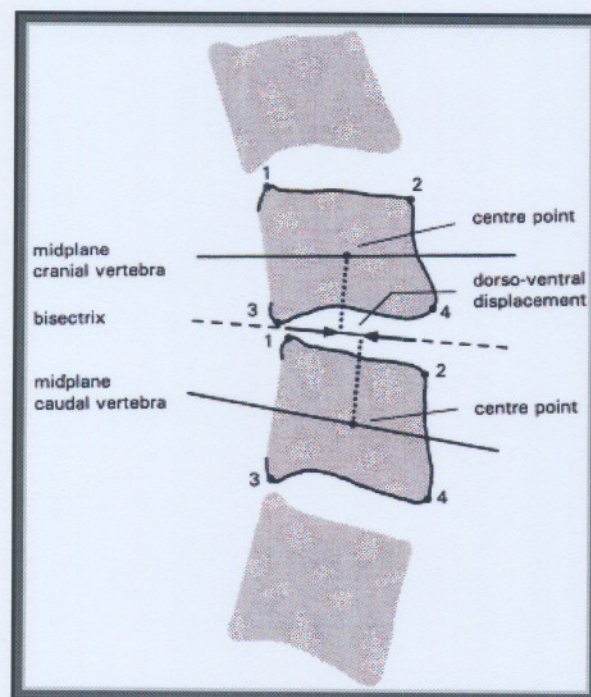


Figure 6.9: Method for measuring extension angle for a motion segment in the cervical spine region.

6.8.4.3 Analysis of Digitised X-ray Films

The marked x-ray films were scanned into a computer using a Siemens system. The scanned films were then digitised with computer software (Centricity Radiology RA 600). The angles between the midplanes of each motion segment were then measured for the flexion and extension views, utilising the same computer software program. The translation was also measured as standard distance units by the program. The necessary measurements for each subject were then recorded on a spreadsheet.

6.8.5 Manual Physiotherapy Treatment Technique

Studies investigating the efficacy of physiotherapy in the treatment of neck pain have been disappointing. Reviewing the literature of treatment modalities used by these investigators, manual therapy were not included as part of the treatment protocol in any of the found studies and further no mention was made of correcting biomechanical dysfunction. Systematic reviews published in 1996 and 1997 concluded that there is little information available from clinical trials to support many of the treatments for mechanical neck pain and that conservative interventions have not been studied in enough detail to assess the efficacy adequately (Alaranta *et al*, 1994; Holmström *et al*, 1992 and Winer, 1971).

The number of randomised control trials in the field of neuromusculoskeletal therapy is increasing, yet there is still a comparatively small quantity of evidence available to support many aspects of practice and policy (Moore & Jull, 2003).

For this study the treatment technique as taught by Rocabado (1999) in his Module 2 course was performed. The subjects were treated two to three times during the first two weeks of the study and then once a week for the following two weeks until the follow-up x-rays were performed and clinical findings were documented for each treatment (Appendix E). When the assessment of motion segment analysis indicated the correction of the dysfunction, the subject started with phase one of the therapeutic exercise programme for the rehabilitation of the cervical spine muscles. Each player was provided with a copy of phase one of the neck rehabilitation programme in his

choice of Afrikaans or English as well as all the equipment needed to perform the programme.

Technique

The researcher evaluated the motion segments of the cervical spine in a sitting position prior to the start of the treatment session and documented the findings on a treatment sheet for each of the subjects. The spinous process of the inferior vertebra of the motion segment to be treated was then palpated. In the event of biomechanical dysfunction of the right facet joint the cervical spine was then rotated to the opposite side, in this example to the left, until movement could be detected at the level of the inferior vertebra. The cervical spine was then laterally bended to the left until the spinous process of the inferior vertebra tilted to the right. The researcher then performed resistance to right rotation adapting to the strength of the subject so as not to get movement at the level intended to be corrected. The resistance was held for a period of six seconds and the sequence repeated six times. The researcher then continued to treat the remainder of the motion segments on the same side, if one than one level were affected. The researcher then continued to correct the levels on the left, with rotation and side bending now performed to the right with resisted left rotation (Rocabado, 1999).

The subject was then asked to lie prone on the treatment plinth and the researcher checked for any muscle spasm and trigger points as well as other myofascial symptoms, which were then treated using general manual therapy techniques. It was however not expected that the subjects should have any major signs, since they have not had any previous injury and did not suffer any pain at the time of the study. The subject was then asked to lie supine and the anterior structures of the cervical spine were evaluated for any muscle spasm or other pathological signs. The treatment technique was then repeated in supine. The treatment was noted in the treatment sheet of the subject and following the treatment the cervical spine motion segments were evaluated again and documented. In the event of correction of the segments prior to the four weeks allocated to the treatment period prior to the follow-up x-rays the

subject was evaluated once a week to make sure than the segments remained without dysfunction.

6.8.6 Therapeutic Exercise Programme for Correction of Biomechanical Dysfunction

The therapeutic exercise programme for the correction of biomechanical dysfunction was developed by the researcher based on the manual physiotherapy treatment technique as used for the Group 1 players who received physiotherapy (Chapter 4:86). The therapeutic exercise programme for the correction of biomechanical dysfunction was performed by Groups 2 and 3. The programme was executed by the subjects without the constant supervision of the researcher for the period prior to the second set of x-rays.

The subjects were asked to perform the entire programme at least three times per week, preferably four times. Each of the sequences had to be performed three times and the resistance to the rotation movement had to be held for 6 seconds. The following section is a copy of the corrective exercises as was given to the subjects in Groups 2 and 3. Each of the subjects was provided with a copy of the exercise programme in his choice of Afrikaans or English , as well as the necessary equipment to perform the programme.

EXERCISE SEQUENCE TO THE RIGHT

The player was asked to clutch a tennis ball under is chin and turn his neck to the right, until it felt as though the tennis ball was going to fall out. He was then instructed to drop his right ear towards his right shoulder and to place one finger of his left hand on his left temple. He was then asked to turn his neck to the left while resisting the movement with his finger so that no movement occurs. This isometric contraction was instructed to be held for six counts and had to be repeated three times (Figure 6.10).

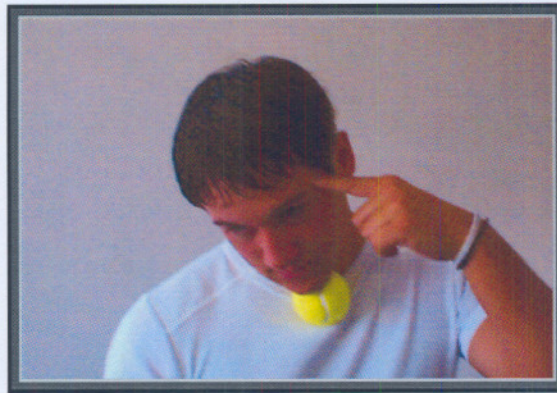


Figure 6.10: Illustration of the first movement pattern included in the therapeutic exercise programme performed by the players of Groups 2 and 3.

For the second movement pattern of the therapeutic exercise programme the player was asked to move the tennis ball to the middle of his clavicle and clutch the tennis ball under his chin. He was then asked to turn his neck to the right as far as he could hold the tennis ball and then to drop his right ear to his right shoulder. He was then instructed to place one finger of his left hand on his left temple and to turn his neck to the left while resisting the movement with his finger so that no movement occurred (Figure 6.11).

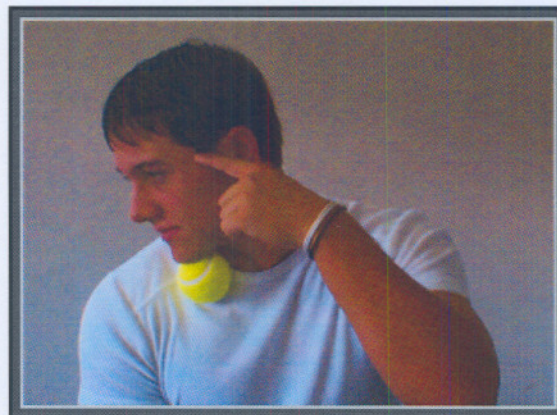


Figure 6.11: Illustration of the second movement pattern included in the therapeutic exercise programme performed by the players of Groups 2 and 3.

The players were then asked to perform the same exercise sequence to the left. These therapeutic exercise sequences were repeated for four weeks. The therapeutic exercises remained the same except for the amount of resistance to neck rotation. The players had to resist rotation with two fingers during week two of the programme, with three fingers during week three and with the palm of the hand during week four of the therapeutic exercise programme. The second set of x-rays followed the completion of the therapeutic exercise programme for the correction of biomechanical dysfunction.

6.8.7 Neck Rehabilitation Programme

The following neck rehabilitation programme was developed by the researcher according to the literature reviewed earlier (Chapter 4:88). The neck rehabilitation programme was divided into three phases of rehabilitation with progression from one phase to the other. Phase one exercises were performed by the subjects prior to the second x-ray procedure. Phase one exercises were performed by Group 1 as soon as the cervical dysfunction was corrected according to the validated manual physiotherapy evaluation technique and by Groups 2 and 3 as part of the Therapeutic Exercise Programme. Following the second set of x-rays the subjects performed phase two of the neck rehabilitation programme for a period of four weeks and then went on to phase three if they could successfully complete all the exercises of phase two. Phase three exercises were then performed until the end of the study when the final set of x-rays was taken. At this time a final questionnaire had to be completed by the players concerning their compliance to the programme as well as possible adverse effects of the rehabilitation programme (Appendix F). The complete neck rehabilitation programme is available from the researcher.

One of the biggest concerns during the study was thought to be the compliance of the subjects. To minimise non-compliance the researcher decided to include the exercise programme as part of the payer's training sessions. The captain of each team of the teams that included study subjects was taught the exercises and the team was provided with all the equipment needed to perform the exercises. Each subject was also phoned

on a weekly basis by a person taught in protocol for enquiring about their compliance with the exercise programme.

Each element of the neck rehabilitation will be described in the following section with the progression of phase one to three illustrated accordingly. The players were requested to perform the exercises at least 3 times, preferably 4 times per week.

6.8.7.1 General Principles when Performing the Rehabilitation Programme

The following principles remained the same for all three phases of the neck rehabilitation programme.

Breathing

The players were informed to inhale through their noses and to exhale through their mouths. They were asked to concentrate on controlled breathing and to focus on their “inner core”. It was explained to them that this filtered out all the outside distractions and allowed the necessary control for the exercises. Relaxation while performing these exercises was emphasised (Chapter 4:113).

The players were asked to relax their neck and shoulder region and that while breathing the shoulder blades had to point towards their lower backs. They had to concentrate on using the lower ribs, muscles and diaphragm while breathing by placing their hands or a towel around the lower ribs. They were asked to feel their ribs moving on in- and expiration. They were advised not to force deep breathing as it may do more harm than good and that during expiration their hands had to return to their original position.

Neutral Position of the Tongue

The players were requested to place the tip of their tongues against the back of their front teeth as when saying the “n” sound for example no. This ensured that their jaws

remained relaxed and that the upper cervical spine region remained in the correct position (Rocabado, 1999).

Core Stability

This is the first basic step in the dynamic stabilisation of the vertebral column and the management of optimal posture. The players were asked to maintain core stability while performing all the cervical spine exercises. They were requested to lie on their backs with both knees bent. They subsequently had to inhale deeply and on expiration they had to pull their bellybuttons in and up. The players were instructed to keep the red triangle area, as illustrated in Figure 6.12, flat. The muscle contraction had to be maintained for as long as possible. The illustration of the transversus abdominis muscle (Figure 6.12) demonstrated to the player the specific muscle they needed to strengthen to provide support for their lower backs.

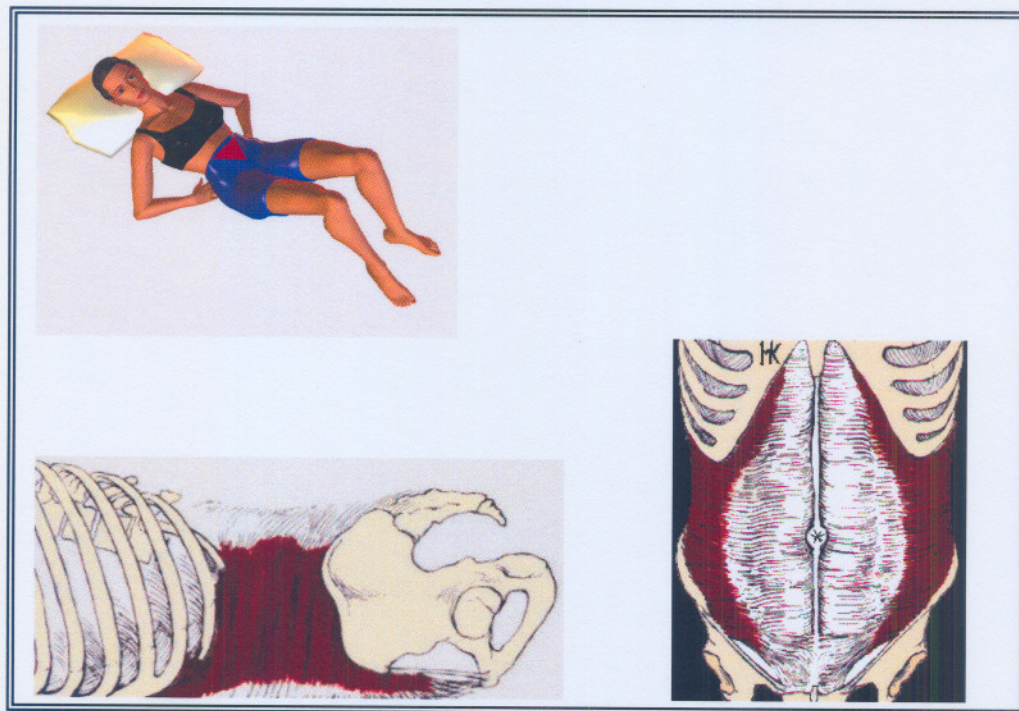


Figure 6.12: Core stability exercise using transversus abdominis.

Shoulder Stability

In addition to core stability the players were also asked to maintain shoulder girdle stability throughout the rehabilitation programme. They had to place a ball between their shoulders and the wall and then had to visualise that their shoulder was the centre of a watch face. The stability position of the right shoulder was said to be the 7 o' clock position and the 5 o' clock position for the left shoulder (Figure 6.13). They were advised that they could improve their shoulder mobility by slow controlled movements through all the hours of the watch. The emphasis had to be on control and not speed.

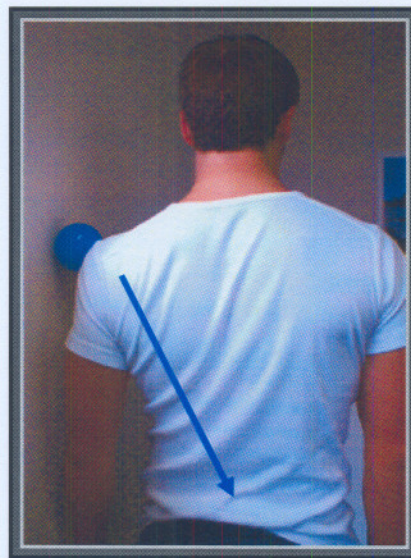


Figure 6.13: Watch exercise for shoulder girdle stability.

6.8.7.2 Strengthening and Re-establishing Neuromuscular Control

Deep Neck Flexors

They players were requested to lie on their backs with their arms by their sides, with a small rolled-up towel in the hollow of their necks. Subsequently they were asked to pull their scapulas down towards their lumbar spines and to tuck their chins in and lift

their heads only one centimetre from the ground (Figure 6.14). They were advised not to use the sternocleidomastoid muscles for this movement, but rather the deep cervical flexor muscles (Chapter 4:118). The position had to be held for six counts, or until the muscles fatigued, and the exercise had to be repeated six times.



Figure 6.14: Phase one deep cervical flexor strengthening exercise.

Once they could perform this exercise without fatigue of their deep neck muscles, they were requested to progress the exercise by continuing to perform flexion of the neck, attempting to place their chins on their chests. The idea was that they had to roll their necks up segment for segment (Figure 6.15 left and right). The emphasis was placed on control of the movement and not on speed.



Figure 6.15: Progression of phase one deep cervical flexor strengthening exercise.

The deep cervical flexor muscle exercise progressed in phase two and three of the rehabilitation to flexion movement against resistance. A green Theraband was used for phase two and a silver Surgical Tubing was used for phase three. The flexion movement remained the same as during phase one of the rehabilitation programme. The Theraband or Surgical Tubing, given to them by the researcher, was placed around their heads and then thread underneath their scapulas and across their chests so that they could hold the Theraband or Surgical Tubing with one hand. They were asked to tuck in their chins, followed by neck flexion, vertebra by vertebra (Figure 6.16).



Figure 6.16 Phase two deep neck flexor exercise with Theraband resistance.

Proprioceptive Neuromuscular Facilitation (PNF) Movement Pattern

The proprioceptive neuromuscular facilitation movement pattern for the neck was taught to the players during phase one of the rehabilitation programme. The subjects were asked to lie on their stomachs with their legs together. They had to create a diamond shape with their arms by placing their fingertips together just above their foreheads, with elbows open and their shoulders relaxed. They were instructed to rotate their necks to the side aiming the tips of their noses to the tips of their shoulders

(Figure 6.17 left). The movement pattern required them to then rotate their necks to the opposite side, following a diagonal line, ending with their noses pointing to the ceiling (Figure 6.17 right).



Figure 6.17: Proprioceptive neuromuscular facilitation movement pattern without resistance for phase one of the rehabilitation programme.

This exercise was progressed to performing this PNF movement pattern against resistance. The resistance required for phase two of the rehabilitation programme was provided by the green Theraband. The players had to tie one end to fit around their heads. They were asked to hold the other end with one hand so that when they moved their necks from the nose down position there would be resistance against the movement (Figure 6.18 left). The exercise was repeated six times to each side. They then had to change the loose end of the Theraband to the opposite hand, subsequently resisting the movement from the nose up position to the nose pointing towards the tip of the shoulder position. This part of the exercise also had to be performed six times to each side (Figure 6.18 right).



Figure 6.18: Proprioceptive neuromuscular facilitation movement pattern with resistance for phase two of the rehabilitation programme.

During phase three of the rehabilitation programme the PNF movement pattern remained the same as for phase two but resistance was now provided by the silver Surgical Tubing. At the end of the movement the players had to perform 10 small oscillations attempting to increase their range of motion every time, by aiming their noses to a target further on the wall or ceiling. If this was no longer a challenge they were asked to increase the speed of the movement. The fast exercise had to be repeated 20 times. They subsequently had to change the loose end of the Surgical Tubing to the opposite hand and perform the opposite movement as explained during phase two, again increasing their range of motion and speed of the exercise (Figure 6.19 left and right).

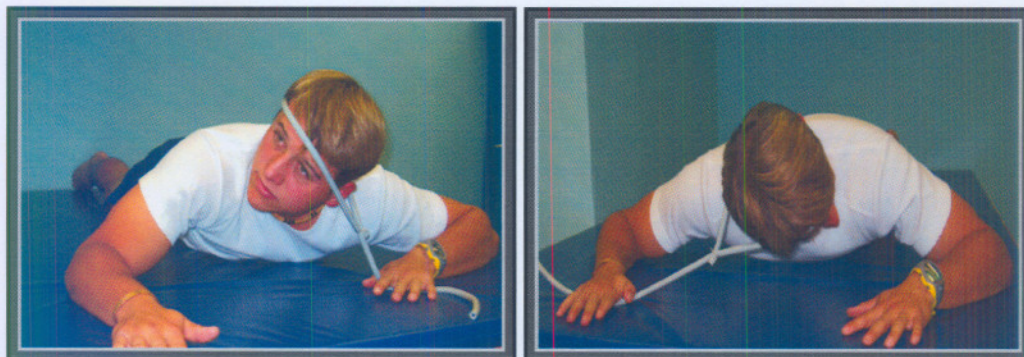


Figure 6.19: Proprioceptive neuromuscular facilitation movement pattern with resistance for phase three of the rehabilitation programme.

6.8.7.3 Cervical Spine Mobilising Exercises

Mobilising Exercise for Neck Rotation

For phase one the player were instructed to pull the green Theraband across their chests with the shoulders in approximately 90 degrees of abduction. They then had to stabilise their shoulder girdles and turn their necks slowly to the right, trying to look at the tips of their shoulders. Subsequently they had to slowly turn their necks to the left and repeat the movement six times to each side (Figure 6.20 left and right).



Figure 6.20: Mobilising exercise for cervical rotation for phase one of the neck rehabilitation programme.

Mobilising Exercise Spine Extension

During phase two of the neck rehabilitation programme the following spine extension mobilising exercise was included. The players had to lie on their stomachs with their arms by their sides. They had to proceed by lifting both legs up as far as they comfortably could without straining their lower backs (Figure 6.21 left). This position had to be held for 20 - 30 seconds, while breathing evenly. After returning to the starting position they subsequently had to lift their upper bodies, with the support of the arms, without straining their lower backs. It was emphasised that they had to keep their hips on the floor. Again this position had to be held for 20 – 30 seconds while breathing evenly (Figure 6.21 right).

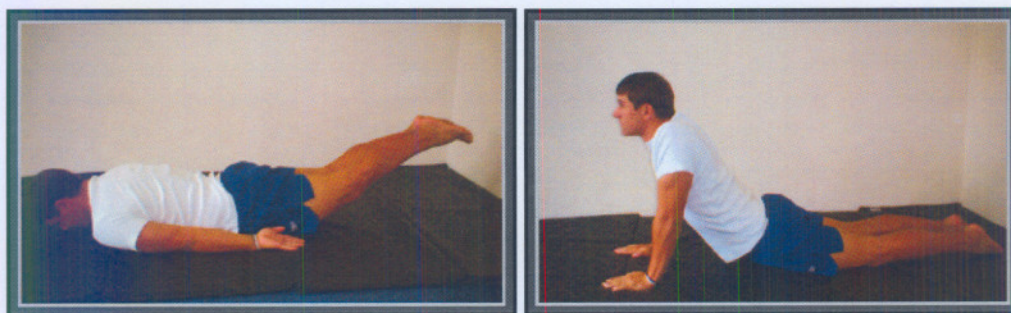


Figure 6.21: Mobilising exercise for extension of the spine for phase two of the neck rehabilitation programme.

Mobilising Exercise for Spine Flexion

For phase three of the neck rehabilitation programme a spine flexion mobilising exercise was included. The player were instructed to draw their knees up to their chests while lying on their backs. They had to tuck their chins in to their chests so that their spines assumed a C-shape. A rocking movement from head to your sacrum had to be done while maintaining the C-shape of their spines and this rocking movement had to be repeated 10 times (Figure 6.22).

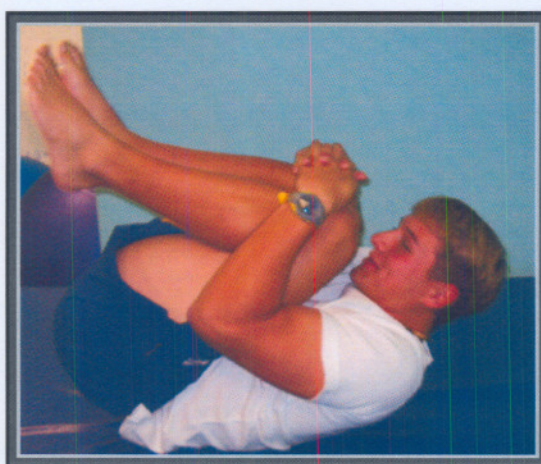


Figure 6.22: Mobilising exercise for flexion of the spine for phase two of the neck rehabilitation programme.

6.8.7.4 Neck Stability Exercises

Neck Stability Exercise in Prone

During phase one of the neck rehabilitation programme the following neck stability exercise was taught to the players. They had to lie on their stomach with their arms by their sides and their legs together. They were instructed to inhale to prepare for lengthening through their spines while tucking in their chins while holding a tennis ball under their chins. On exhalation they were instructed to stabilise their shoulder girdles and then to stretch with their fingers towards their toes and lifting their upper bodies and arms off the floor, while holding the tennis ball tucked under their chins. This position had to be held for six seconds and repeat six times (Figure 6.23 left and right).

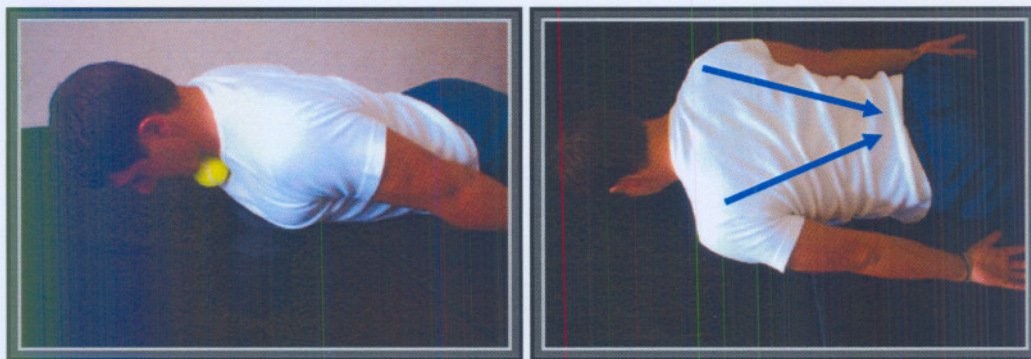


Figure 6.23: Phase one neck stability exercise included in the neck rehabilitation programme.

For phase two resistance was added to the neck stabilising exercise described above. For phases two and three the players had to move their arms to under their faces while positioning the green Theraband or silver Surgical Tubing around their heads. Their legs had to remain together. They still had to prepare for lengthening through the spine while holding the tennis ball under their chins. For phase two the players were instructed to hold the loose end of the green Theraband in their hands and on exhalation to push up against the resistance of the Theraband. They had to lift their heads up and back as far as possible and the exercise was repeated 10 times (Figure

6.24 left). For phase three this exercise was progressed to resistance with the silver Surgical Tubing and if this was no longer a challenge for the players they had to perform the exercise with speed (Figure 6.24 right).

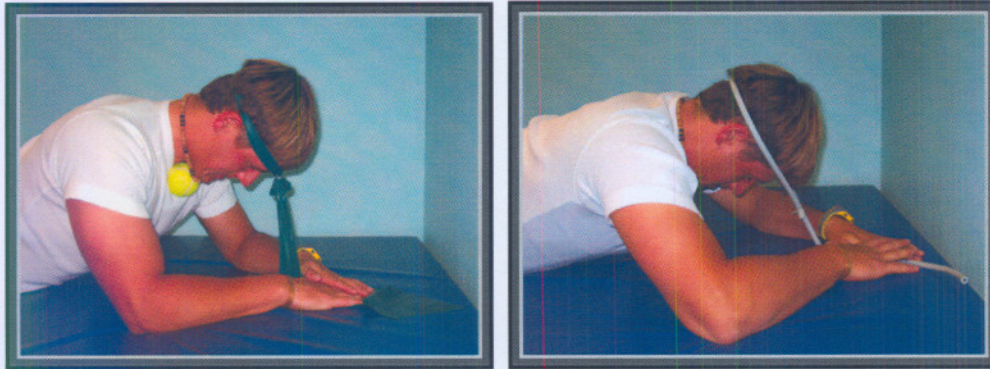


Figure 6.24: Phase two and three neck stability exercise included in the neck rehabilitation programme.

During phase two and three of the neck rehabilitation programme the players were taught how to perform a shoulder and head stands. The final steps of the shoulder and head stands were only performed during phase three of the rehabilitation programme.

Shoulder Stand Neck Stability Exercise

The following sequence was demonstrated to the players for the shoulder stand. The players were instructed to start the sequence by lying on their backs with their palms on the floor and their legs together. The next step was to press down with their palms beside their bodies and raise their legs to 90°, attempting to tilt their legs towards their chests in a pendulum like movement of their legs. This was followed by exhaling and gently lifting their buttocks and backs off the floor. As their backs were raised, they had to bend their arms and use their hands to support their raised bodies. Normal breathing had to be maintained throughout the sequence. The following part of the sequence was to press their palms forward to straighten their backs while pointing their toes and pulling their chests to their chins. This position was initially held for 30 seconds while slowly increasing the length of time the pose was held as they became stronger. From the phase 2 shoulder stand the players progressed to phase three by

slowly lowering both legs to the floor as far as they could. The players were asked to attempt to touch the floor with their toes, keeping their knees straight, without injuring their spines. If they were unable to keep their knees straight because of short hamstrings, they were permitted to bend their knees slightly and continue to lower their legs to the floor (Figure 6.25).



Figure 6.25: Shoulder stand sequence for neck stability included for phase two and three of the neck rehabilitation programme.

Head Stand Neck Stability Exercise

The head stand sequence will be detailed in the following section. The importance of closed kinetic chain exercises have been stated earlier (Chapter 4:128). It was explained to the players why it was important for them to be able to perform a head

stand. It was explained to them that if they were involved in a tackle where their heads were driven into the ground their neck muscles must be able to support the weight of their bodies. It was also explained that the same principle applied when a scrum collapsed or in a ruck and maul situation.

The players were instructed to sit comfortably and to focus on the exercise. The sequence was started with them bending forward and rest their elbows and forearms on the floor in front of them. They had to keep their elbows pressed down while moving their hands forward so that their fingers could be interlocked to make a tripod shape with their palms and forearms. This was followed by bringing the crowns of their heads down and placing them on the floor, with their palms pressed on the back of their heads. They then had to raise their hips while walking forward on their toes until their backs were straight. This was followed by a gradual reduction of the pressure on their heads, by pressing down on their elbows and forearms to stabilise their trunks. Breathing had to be even and the position initially had to be held for a period of 20 – 30 seconds. At this stage for phase two they were informed to gently release the position and return to sitting on their haunches. For phase three the players were asked to lift their toes off the floor and straighten their bodies for the full head stand position (Figure 6.26).

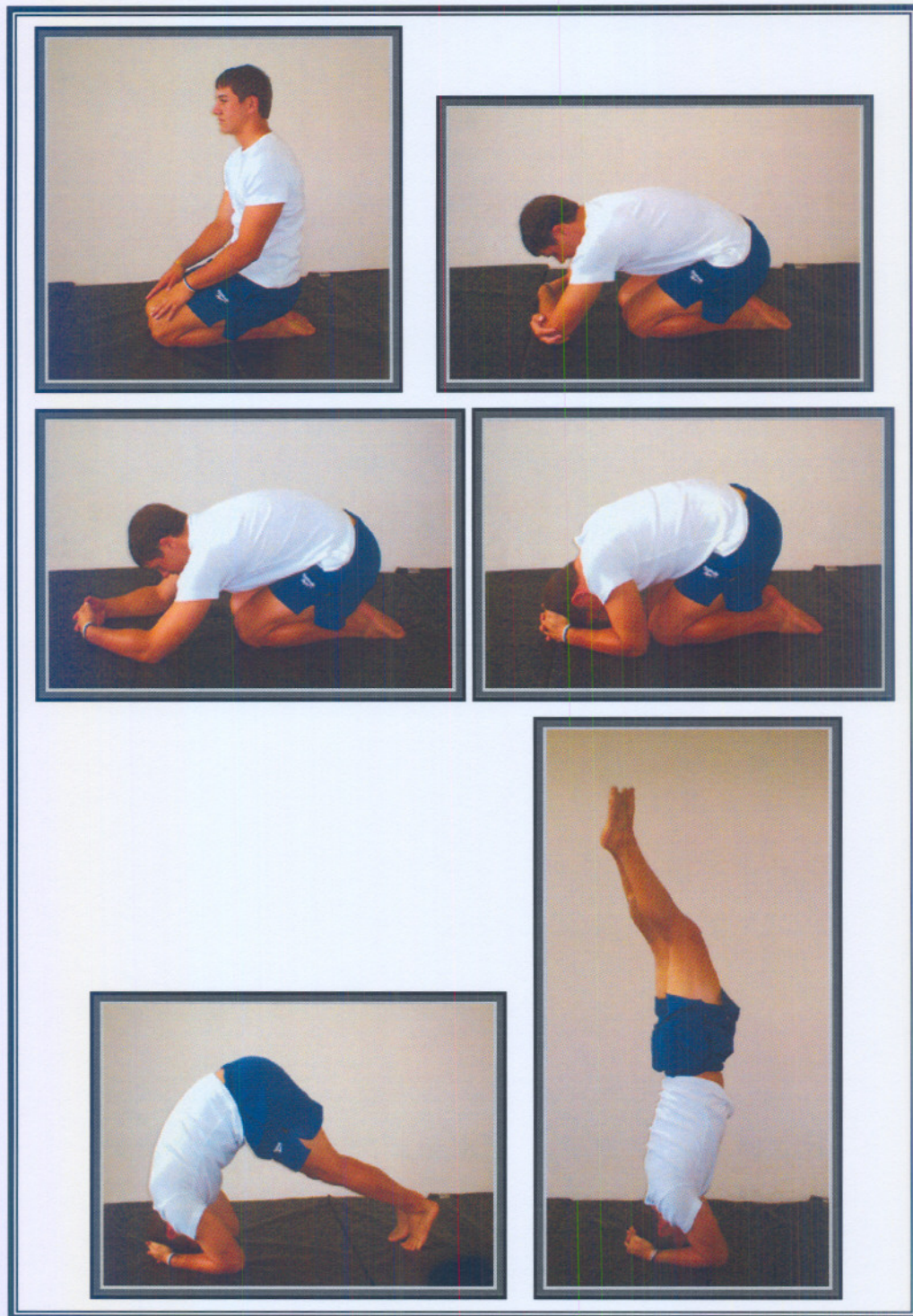


Figure 6.26: Sequence for the head stand included in phase two and three of the neck rehabilitation programme.

Perturbation For Neck Stability

It was stated in the literature review that it was important for dynamic stability of the spine to include perturbation type exercises in rehabilitation (Chapter 4:121). The following exercise was used in phase three of the neck rehabilitation position, using one of the stages of the shoulder stand sequence (Figure 6.27). The players were asked to keep their balance in this position while another player gently pushed them in different directions. They had to resist the pressure while and had to maintain their balance. Once the players felt confident that they were strong enough, they could ask the other player to try to push them off balance and they tried to maintain their balance. The players were cautioned not to injure one another.

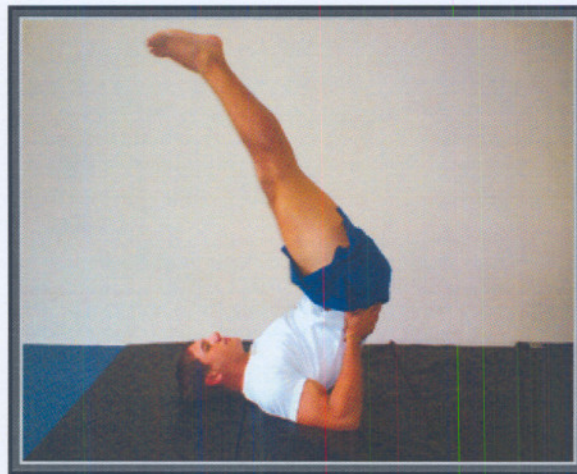


Figure 6.27: Shoulder stand position used for the perturbation exercise included in phase three of the neck rehabilitation programme.

Closed Kinetic Chain Dynamic Stability Neck Exercise

The final neck stabilising exercise included in phase three used one of the positions assumed during the head stand (Figure 6.28). This exercise could be described as a closed kinetic chain, dynamic stability exercise and as such is very important to the schoolboy rugby player (Chapter 4:110). In this head stand position they players were asked to imagine that their heads were in the centre of a watch face. If they struggled with imagining this, they could draw a cross on the floor to help them perform this

exercise correctly. They were instructed to roll their heads from the centre to the 12 o'clock position and then from the centre to the 6 o'clock position. They had to move as far as they felt comfortable with. This movement was followed by moving from 9 o'clock to 3 o'clock, again as far as they felt comfortable with. When this was no longer a challenge for them, they could progress by moving through all the hours of the watch. Initially they were instructed to perform these movements slowly and then to increase the speed of the exercises until they could perform the movements quickly without discomfort.

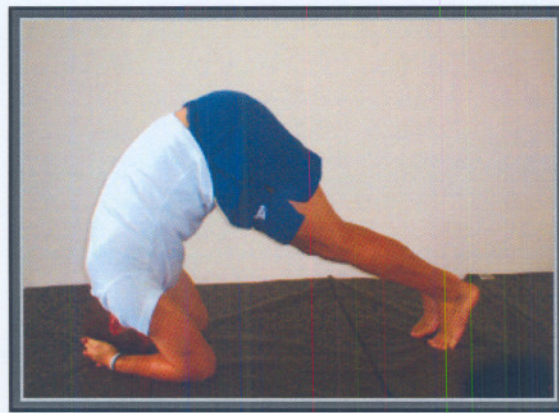


Figure 6.28: Position assumed for the closed kinetic dynamic stability exercise included in phase three of the neck rehabilitation programme.

6.8.7.5 Flexibility Exercises

The players performed static stretches for phase one and two of the rehabilitation programme and ballistic stretches were included in phase three of the rehabilitation programme. The starting position and method of stretching remained the same for all three neck stretches, only the position of the head changed. All stretches were held for 30 seconds and repeated 3 times each.

Starting Position and Method For all Stretches

The players were instructed to sit on one hand, the side that they were going to stretch, with their backs straight and their shoulders relaxed. They subsequently had to

position their necks as explained for each of the stretches. They then had to hold their necks in this position with the other hand. It was strongly emphasised that they were not permitted to pull on their necks. To feel the stretch, the players had to pull down their scapulas by bending their elbows of the hands they sat on (Figure 6.29).

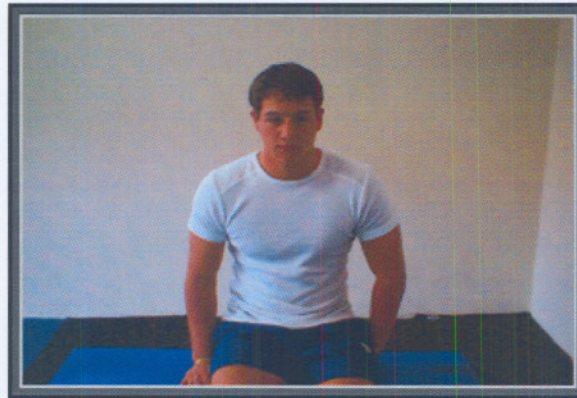


Figure 6.29: Starting position of all the stretches for all three phases of neck rehabilitation.

Stretch for the Lateral Neck Muscles

The players were instructed to perform lateral flexion of their necks, as far as was comfortable, while maintaining a good sitting posture. Instruction was given to hold their heads as explained and to pull down their scapulas. They were advised that they should feel the pull on the side of their necks (Figure 6.30 left). For phase three the players had to perform a ballistic version of this stretch by completing 10 small oscillation movements with their heads (Figure 6.30 right).



Figure 6.30: Stretch for the lateral neck muscles included for phases one, two and three of the rehabilitation programme.

Stretch for the Posterior Muscles of the Neck

Instructions were given to the players to do perform a combined movement of flexion, rotation and lateral flexion away from the side being stretched, until they felt the muscles pull at the back of their necks (Figure 6.31 left). This position had to be held with their elbows bent, as explained earlier (Chapter 6:200). For phase three the players had to perform a ballistic version of this stretch by completing 10 small oscillation movements with their heads (Figure 6.31 right).



Figure 6.31: Stretch for the posterior neck muscles as performed during phases one, two and three of the rehabilitation programme.

Stretch for the Lateral and Prevertebral Neck Muscles

While maintaining the end position of the previous stretch the players were instructed to rotate their heads to the side being stretched, while holding their heads and pulling down their scapulas (Figure 6.32 left). They were told to feel the stretch on the side and front of the neck. For phase three the players had to perform a ballistic version of this stretch by completing 10 small oscillation movements with their heads (Figure 6.32 right).



Figure 6.32: Stretch for the prevertebral and lateral neck muscles as performed during phases one, two and three of the rehabilitation programme.

The following section will detail the nerve mobilising exercises as performed during phases one, two and three of the neck rehabilitation programme.

6.8.7.6 Nerve mobilising exercises

Phase One Nerve Mobilising Exercise

The nerve mobilising exercise for phase one of the rehabilitation programme were instructed as follows: The players were asked to sit with their body weight supported on their arms with their palms flat on the floor and their fingers pointing posteriorly with their thumbs to the lateral side. They then had to straighten their elbows while maintaining the stability position of their scapulas. In this position they were

instructed to try and elevate their sternums while inhaling, and this position was held for six seconds. They could relax while exhaling and then they and to repeat this exercise six times (Figure 3.33).

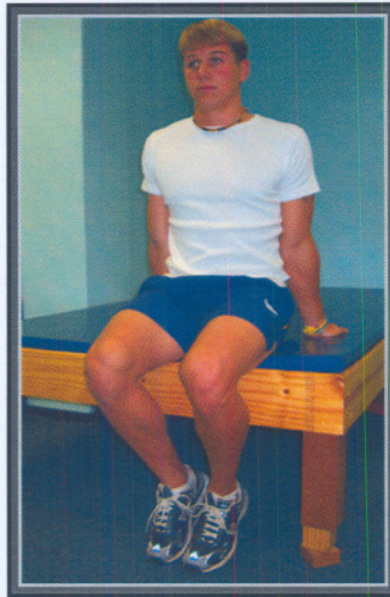


Figure 6.33: Nerve mobilising exercise for phase one of the rehabilitation programme.

Phase Two Nerve Mobilising Exercise

The nerve mobilising exercise included for phase two of the rehabilitation programme required that the players sit with their legs straight in front of them with their knees flat on the ground (Figure 6.34 left). They subsequently had to straighten their left hands in front of them with their elbows straight and their wrists extended so that their fingers pointed superiorly. With their right hand they had to pull their fingers (including the thumb) posteriorly until they could feel the pull down their arms (Figure 6.34 right). This position was held for 10 seconds. For the second part of the exercise they had to elevate their arms with their elbows next to their ears, making themselves as tall as possible. This position was held for 10 seconds.

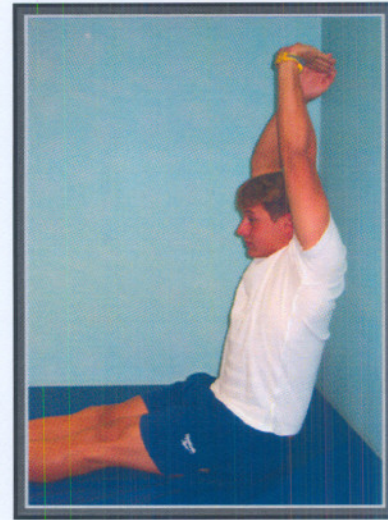
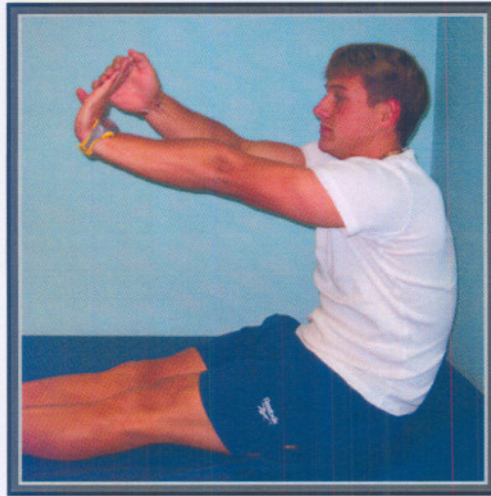


Figure 6.34: Phase two nerve mobilising exercise included in the rehabilitation programme.

Phase Three Nerve Mobilising Exercises

Two nerve mobilising exercises were included in phase three of the neck rehabilitation programme. The first required the players to sit with their legs straight out in front of them with their knees flat on the ground. They then were instructed to cross their arms at their elbows and to interweave their fingers, palms together and hold this position for 10 seconds (Figure 6.35 left). Subsequently they had to elevate their arms and again hold for 10 seconds (Figure 6.35 right).



Figure 6.35: First nerve mobilising exercise included in phase three of the rehabilitation programme.

For the second nerve mobilising exercise included in phase three of the rehabilitation programme the players were instructed to sit with their palms together and their elbows and shoulders at the same height. They then had to move slowly to the left until their hands were in front of their shoulders (Figure 6.36). They had to feel the pull at the back of their upper arms and this position was then held for 10 seconds. The same movement was repeated to the right and again held for 10 seconds.

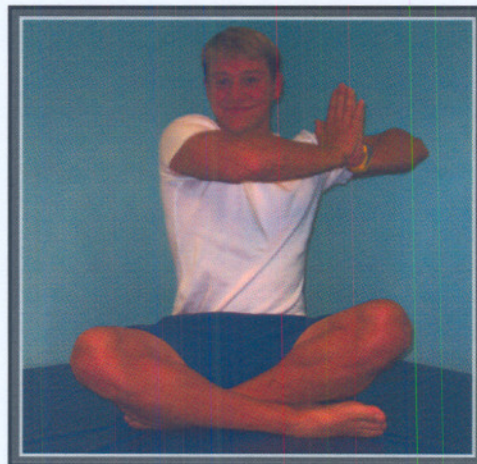


Figure 6.36: Second nerve mobilising exercise included in phase three of the rehabilitation programme.

Balance exercises performed by the players during phases one, two and three will be detailed in the following section.

6.8.7.7 Balance

Phase One Balance Exercise

For any schoolboy rugby player it is of utmost importance to have good balance. The players were instructed to stand on one leg, without their knees touching and with the supporting leg slightly bent. They had to maintain core stability, close their eyes and keep their balance for as long as possible, without putting the other foot down (Figure 6.37). Proprioception was briefly explained to them.

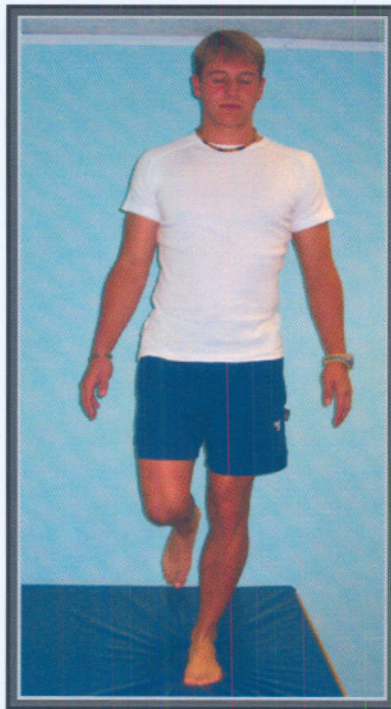


Figure 6.37: Phase one balance exercise included in the rehabilitation programme.

Phase Two Balance Exercise

The balance exercise included in phase two of the rehabilitation programme required the players to stand on one leg and shift their weight forward, backwards, and to both sides, slowly and controlled (Figure 6.38). They could also simulate a passing or kicking movement pattern, pivoting on their supporting leg, to make these balancing exercises more relevant to rugby. Once these movements were easy, they were instructed to perform them with closed eyes.

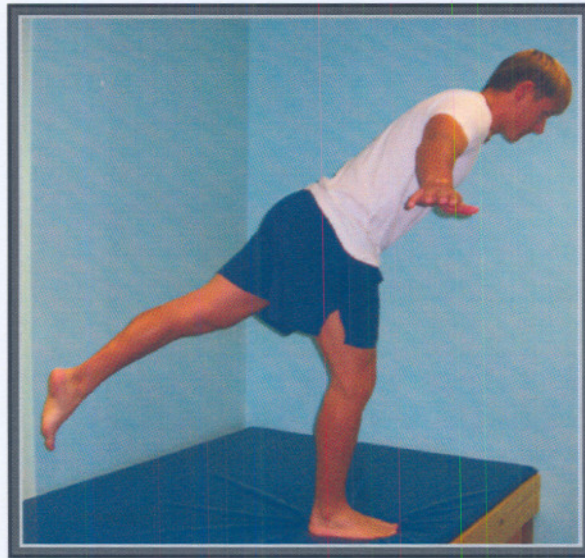


Figure 6.38: Phase two balance exercise included in the rehabilitation programme.

Phase Three Balance Exercise

The performance of the phase three balance exercise required the help of a fellow player. The players were asked to hold onto their Surgical Tubing, with the other player holding onto the other end. Subsequently they had to perform the same balancing exercises as for phase two, the difference being that the other player had to try and pull them off balance. The idea was not for them to pull one another off balance as quickly as possible, but rather for them to gain knowledge concerning their ability to maintain balance their (Figure 3.39). The importance of performing these

exercises shortly after warm-up and not after a physically tiring exercise session was emphasised, since balance and coordination was found to be poor following muscle fatigue, therefore increasing the risk of injury (Chapter 4:137).



Figure 6.39: Phase three balance exercise included in the rehabilitation programme.

6.8.7.8 Player Education for the Neck Rehabilitation Programme

The players were informed of various high risk situations for neck injury and how the rehabilitation programme would benefit in possibly preventing neck injury from occurring in these situations. They were advised that if they were able to perform all the neck exercises described in the neck rehabilitation programme they could be confident that their neck muscles were strong enough to be able to support their cervical spines during these high risk situations.

It was also explained to the players that while they performed the rehabilitation programme they had to imagine phases of play, such as tackling, where each exercise would benefit them and that this was how the brain learned new protective strategies. It was expressed that this would help prepare them to respond effectively, and almost

automatically, during high risk situation, which may arise in a training session or match.

The statistical analyses used for the analysis of the raw data will be provided in the following section.

6.9 Statistical Analysis

The statistical analysis was performed by Prof. H.S Steyn. The data was analysed using the following analyses. Paired t-tests were used to obtain statistical significant differences between the means of first and second X-ray measurements (Thomas & Nelson, 1985). These were followed by calculating the effect sizes of differences in means to establish the practical significance of the results (Cohen, 1988). One-way analysis of variance (ANOVA) was performed on the first X-ray measurements to compare the posture groups. The effect size eta-square was calculated to obtain the practical significance of the posture effect. A Student t-test was done to establish whether the mean measurements of the forward and backward rugby players differed with statistical significance. The effect size of the difference in means was obtained to determine the practical significance. The SAS-system was used to do the data analyses (SAS Institute Inc., 1999; SAS Institute Inc. 2002-2003).

6.10 Summary

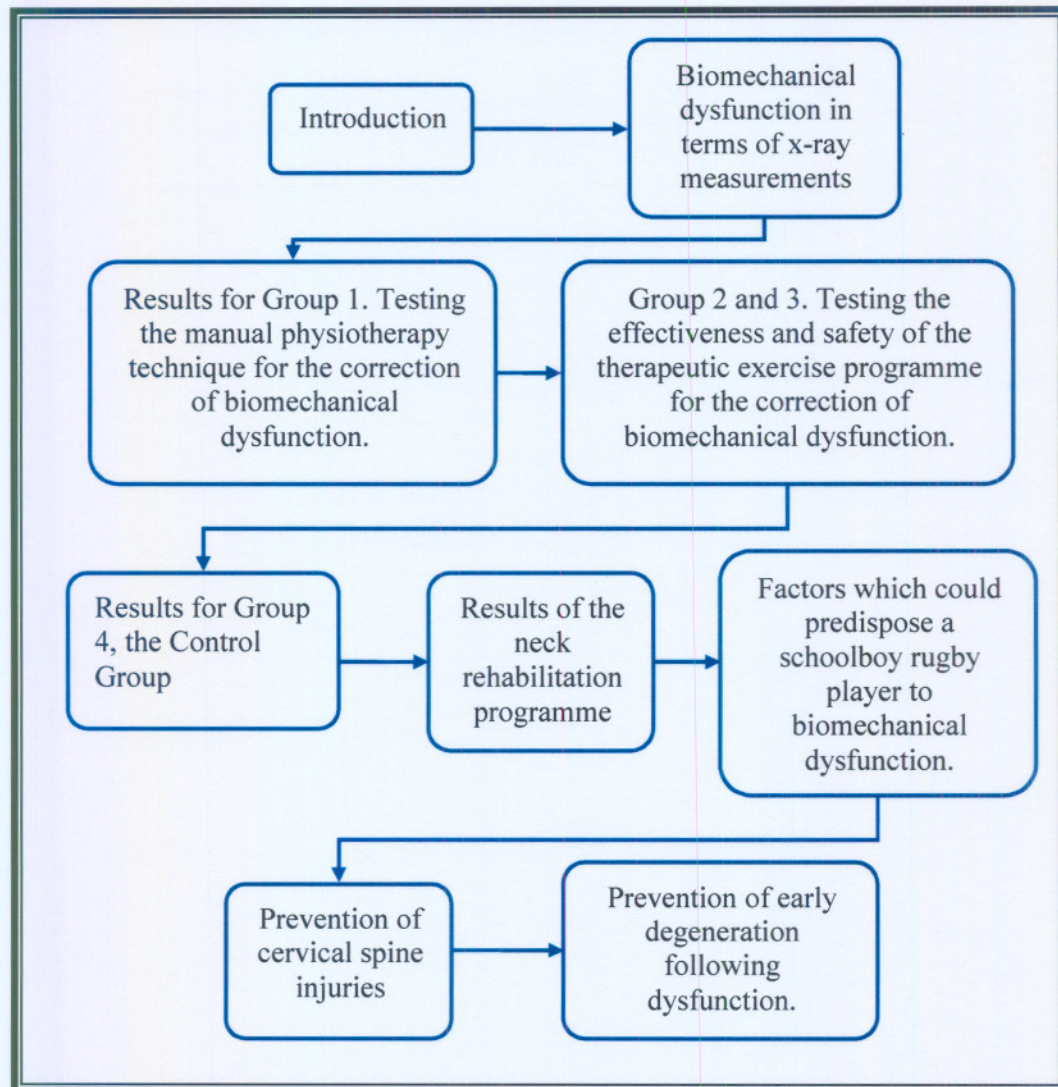
The empirical study chapter included the pilot study performed by the researcher prior to formulating the protocol as outlined in detail in this chapter. The study design, study population and sample as well as the inclusion and exclusion criteria were discussed. Ethical considerations as measurement tools and instruments were detailed. This was followed by the validation of the manual physiotherapy evaluation technique. The manual physiotherapy treatment technique was discussed subsequently followed by details of the therapeutic exercise programme for the correction of biomechanical dysfunction. The neck rehabilitation programme as performed by the subjects was then detailed. The results of the study will be discussed in the following chapter, chapter 7.

Chapter 7

Results and Discussion of the Empirical Study

7.1 Introduction

In this chapter the results of the empirical study will be given and discussed according to the various interventions included in this clinical trial. The following flowchart illustrates the flow of this chapter.



Firstly the term biomechanical dysfunction in terms of the x-ray measurements will be briefly explained to facilitate the interpretation of the x-ray results. The results for Group 1, the group who received manual physiotherapy for the correction of biomechanical dysfunction, will be provided and discussed. This will be followed by a section where the results of Group 2, the group of players with biomechanical dysfunction who performed the therapeutic exercise programme for the correction of biomechanical dysfunction, will be given and discussed. The results pertaining to the safety of the therapeutic exercise programme for Group 3, players without biomechanical dysfunction who also performed the therapeutic exercise programme for the correction of biomechanical dysfunction, will then be stated and considered followed by the results of Group 4, the control group. The neck rehabilitation programme was performed by all the players of Groups 1, 2 and 3 after the second set of x-rays and these results will then be specified. The results of other factors, such as posture, anthropometric measurements and playing position, that could have an influence on the biomechanics of the cervical spine of a subject will be noted and reviewed. This chapter will include the interpretation of the preceding results on the prevention of cervical spinal cord injuries and the prevention of early degeneration of the cervical spine and will end with a discussion on the prevention of cervical spinal cord injuries.

7.2 Interpreting Biomechanical Dysfunction in terms of X-ray Measurements

Biomechanical dysfunction is the crux of this investigation. The researcher identified a biomechanical dysfunction in the cervical spines of schoolboy rugby players during a previous study (Steyn, 2002) and decided to investigate two interventions for the correction of such a dysfunction. The first proposed intervention will be a manual physiotherapy technique and the second proposed intervention will be a therapeutic exercise programme for the correction of a biomechanical dysfunction. Objective x-ray measurements will be compared prior to and following each intervention.

All the selected angles measured on the x-rays will be expressed in degrees and unless otherwise stated a negative sign before an angle will imply the direction of the

rotation only. If the wedge opens anteriorly the angle is counted as positive and if the angle opens posteriorly the angle is counted as negative, in other words a negative angle will indicate that the segment is moving into flexion. For the sake of visually interpreting improvements the negative flexion angles will be negated for the graph illustrations. The translation motion is measured in standard units by the radiographic software, and will be given as such (Chapter 6:179).

As stated before, the movement mostly restricted in schoolboy rugby players is flexion of the motion segments of the lower cervical spine (Chapter 6:170). Therefore correction of the dysfunction would be established by an improvement in the mean flexion angles, as measured on the x-rays, before and after the various interventions studied. Since no restriction of the movement pattern associated with an extension restriction was found, no significant change in the mean angle of extension would be expected.

The angle of rotation was also compared before and after the interventions. These angles were calculated by subtracting the flexion angle from the extension angle (Chapter 4:80). The values for mean angles of rotation provided in Table 7:1 are for subjects with a mean age of 33 without neck pain or pathology. This was the only norm found in the literature (Frobin *et al*, 2002). Even though these values cannot be compared to the current study population, this should however give some indication on what values could be considered as normal for the schoolboy rugby players. A decrease in the angle of rotation should not always be interpreted as a negative result since a hypermobile motion segment is not the ideal.

Table 7.1: Normative values for mean angles of rotation (Frobin *et al*, 2002).

Level	n	Range (°) males
C3/C4	92	11.6 (3.57)
C4/C5	95	14.4 (4.55)
C5/C6	92	12.2 (5.19)
C6/C7	23	9.8 (5.73)

This study will therefore provide the first normative values objectively measured for motion segment analysis, using x-rays, for schoolboy rugby players. For the purpose of this study the means of the various x-ray measurements of the final x-rays performed for Groups 1, 2 and 3 could be used as an indication of the normal values expected for a schoolboy rugby player. The measurements for the control group cannot be used since some of them had biomechanical dysfunction with no intervention to correct this dysfunction.

The translation measurements were also performed for these players, since the physiotherapy evaluation technique studied does not claim to be reliable in determining instability of a motion segment (Chapter 4:81) Instability of the motion segment, as the result of biomechanical dysfunction or degeneration of the disc or facet joints, is believed to be manifested as “slipping” of one vertebra of the motion segment on the other. This could be the result of laxity in the soft tissues of the motion segment and such a motion segment could be considered as hypermobile. The translation distance was measured by the software program used as standard measurement units.

Most of the results were interpreted by means of effect sizes or practical significance (d-values) being calculated using the mean differences between the mean x-ray measurements of the first and the second sets of x-rays. For the purpose of this study and effect size with a d-value of approximately 0.2 was considered to be of small significance. An effect size with d-value of 0.5 was considered to be of moderate statistical significance and an effect size with d-value of more than 0.8 was considered to be highly significant.

The following section will provide and discuss the results of the manual physiotherapy treatment technique (Group 1), explained in detail in the previous chapter (chapter 6:180), used in the correction of the biomechanical dysfunction found in the cervical spines of the schoolboy rugby players.

7.3 Group 1. Testing the Manual Physiotherapy Technique for Correction of Biomechanical Dysfunction.

The effectiveness of the manual physiotherapy interventions will be determined by comparing the objective x-ray measurements performed before and after the treatment for the 25 players with biomechanical dysfunction forming Group 1. The results will be discussed accordingly.

Before the manual physiotherapy treatment commenced a set of x-rays were taken of the cervical spines of these players. The players then received manual physiotherapy treatment and a second set of x-rays were done after a month (Chapter 6:180). The mean values for the different x-ray measurement were calculated for each of the motion segment measured and these results will first be given for flexion, followed by extension, the angle of rotation, and lastly the translation results. The results from these will be followed by the effect sizes (d-values) calculated using the difference in the mean values.

7.3.1 Results of the Flexion angle X-ray measurements for Group 1

The mean angle of flexion of the C6/C7 motion segment was 1.86 degrees for the first x-ray measurements and improved to -5.06 degrees after manual physiotherapy treatment. The effect size (d-value) for this improvement was 2.189, which is highly significant. The improvement for the C5/C6 motion segment was also highly significant with the mean flexion angle improving from -0.8 degrees before the treatment to -5.33 degrees after treatment (d-value of 0.996). Total flexion of all the motion segments measured improved from -9.56 degrees before treatment to -24.44 degrees after treatment (d-value = 1.885). The results for all the flexion angles of the various motion segments as well as total flexion of the motion segments measured are given in Table 7.2 and Figure 7.1.

Table 7.2: Results of the flexion angles for Group 1 before and after manual physiotherapy treatment.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	-6.10	4.20	-7.33	3.07	0.433
C4/C5	-4.52	3.71	-6.72	3.12	0.596
C5/C6	-0.80	4.23	-5.33	2.25	0.996
C6/C7	1.86	3.89	-5.06	2.09	2.189
Total Flexion	-9.56	8.05	-24.44	6.52	1.885

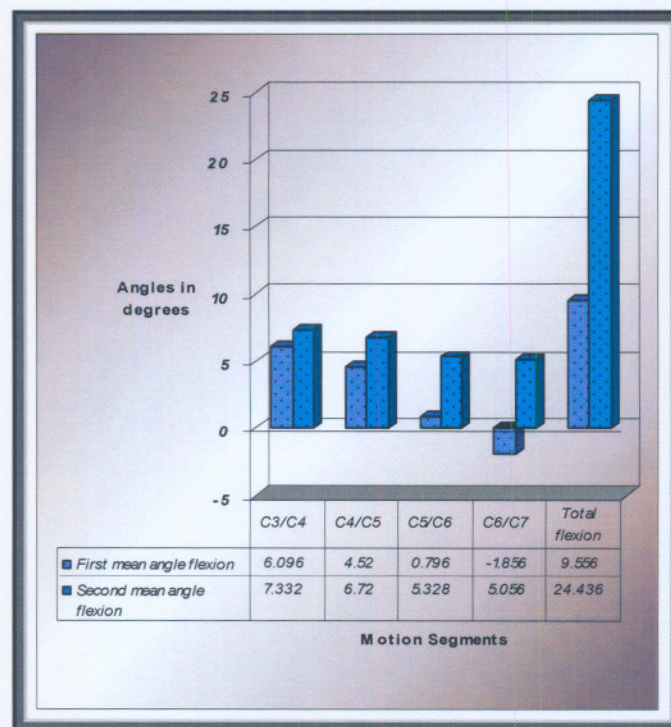


Figure 7.1: Results of the flexion angles for Group 1 before and after manual physiotherapy treatment.

Most of the subjects included in Group 1 had no flexion motion of the C6/C7 motion segment with a mean flexion angle of 1.86 °. These motion segments were thus held in an extension position despite the fact that the cervical spine was moving into flexion. These motion segments improved from being held in extension during a flexion movement to moving into flexion with a mean of -5.06° of flexion.

The fact that flexion movement of the cervical spines of these rugby players proved to be restricted places their cervical spines at a biomechanical disadvantage. When these players perform a flexion movement while playing rugby their cervical spines can therefore not function optimally for protection in high risk situations. The total flexion of the motion segments measured more than doubled with treatment. The practical implication of this for the player is improved biomechanical function of the cervical spine.

7.3.2 Results of the Extension angle X-ray measurements for Group 1

During the physiotherapy evaluation it was found that none of the players presented with restriction of the extension movement of the motion segments tested from C3 to C7. This would imply that the cervical spine motion segments tested for the Group 1 players were all able to move into extension. This was confirmed by the x-ray measurements. The mean extension angle measurements pre-and post treatment showed a small diminution for the C3/C4 and C6/C7 motion segments with d-values of -0.156 and -0.18 respectively of small significance. A small significant increase in mean extension for the C4/C5 and C5/C6 motion segments ($d = 0.053$ and $d = 0.17$ respectively) was found. These results are illustrated in Table 7.3 and Figure 7.2.

Table 7.3: Results of the extension angles for Group 1 following the manual physiotherapy treatment.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	8.66	3.72	8.22	3.59	-0.156
C4/C5	10.50	4.19	10.65	3.73	0.053
C5/C6	9.87	3.65	10.75	5.19	0.170
C6/C7	10.54	6.59	9.57	4.97	-0.180
Total Extension	39.57	9.24	39.20	10.37	-0.052

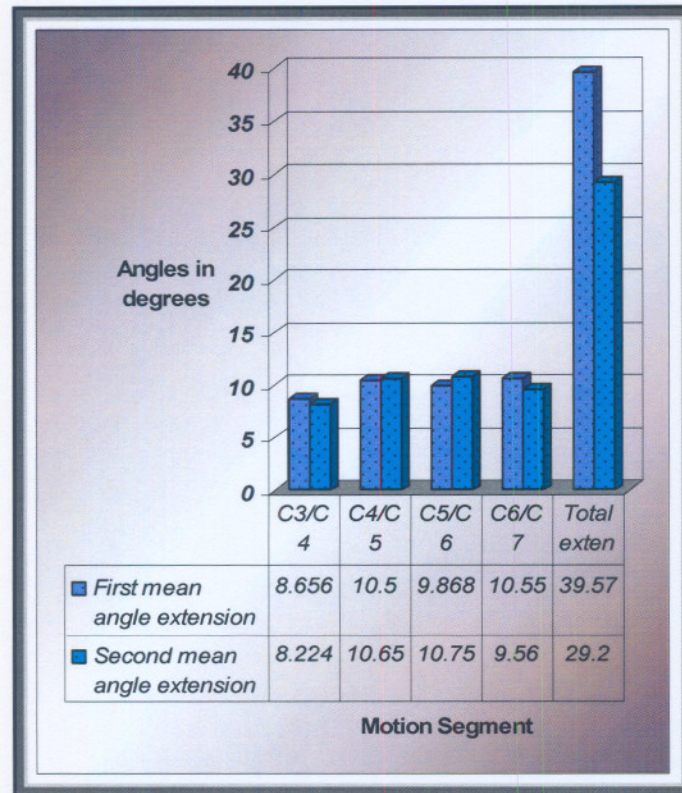


Figure 7.2: Results of the extension angles for Group 1 following the manual physiotherapy treatment.

These results suggest that the cervical spines of the rugby players function optimally during extension of their neck since no restriction for extension movements could be identified. This is in keeping with the literature reviewed where it was found that the most common mechanism of injury to the cervical spine was flexion combined with rotation (Chapter 5:148).

7.3.3 Results for Angles of rotation of Group 1

The various angles of rotation for the first and the second x-ray measurements are displayed in Table 7.4 and Figure 7.3. The improvement of the angles of rotation for the C5/C6 and C6/C7 motion segments was found to be statistically highly significant with effect sizes of $d = 0.961$ and 1.124 respectively. The angles of rotation for C3/C4

and C4/C5 could be considered as close to normal (Table 7.1) and therefore a statistically significant improvement could not be expected.

Table 7.4: Results for the angles of rotation, Group 1, before and after manual physiotherapy treatment.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	14.75	4.93	15.57	4.57	0.192
C4/C5	15.02	5.12	17.37	4.22	0.460
C5/C6	10.66	4.96	16.86	3.87	0.961
C6/C7	8.69	5.66	14.62	4.72	1.124

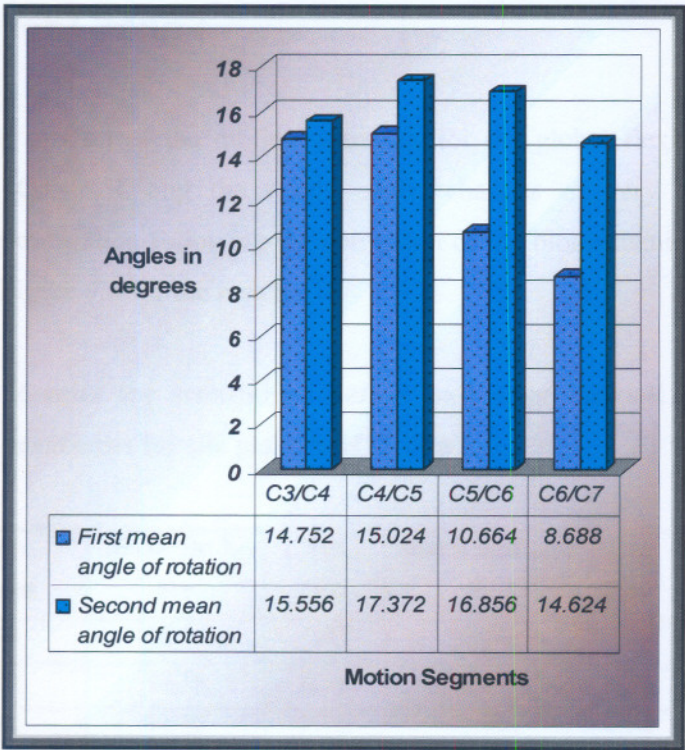


Figure 7.3: Results for the angles of rotation, Group 1, before and after manual physiotherapy treatment.

The fact that the C5/C6 and C6/C7 angles of rotation increased significantly to a more normal value could be interpreted as a more functional motion segment. An improvement in the angle of rotation for any motion segment implies a larger range of motion available to the motion segment for normal biomechanical function. A small angle of rotation suggests that the motion segment is hypomobile and therefore at risk of injury during high load situations that require normal range of motion (Chapter 5:156). This increased range of motion of the motion segments could contribute to the biomechanical function of the entire cervical spine.

7.3.4 Results for the Translation X-ray measurements for Group 1

The translation motion of the motion segments for the global flexion motion was measured for Group 1 and the results show changes of very small practical significance in translation following the correction of the biomechanical dysfunction. See Table 7.5 Figure 7.4 for the results.

Table 7.5: Results for translation before and after manual physiotherapy treatment for the players of Group 1.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	15.43	7.41	15.64	7.54	0.040
C4/C5	13.74	8.34	13.07	7.75	-0.114
C5/C6	14.33	7.75	12.14	8.74	-0.305
C6/C7	11.68	7.8	9.62	5.86	-0.310

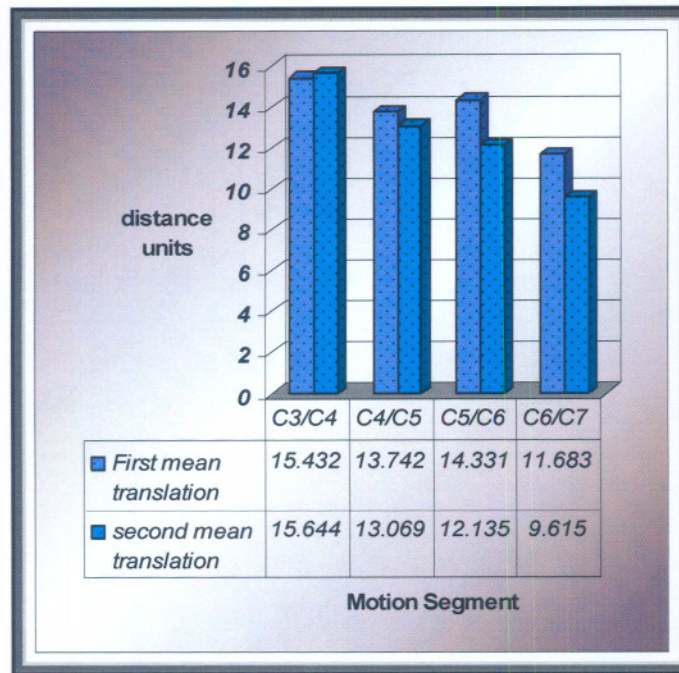


Figure 7.4: Results for translation before and after manual physiotherapy treatment for the players of Group 1.

A reduction in translation was demonstrated which was of very small statistical significance. This does however mean that the motion segments were slightly more stable following the manual physiotherapy treatment. An improvement in stability of the motion segments of the cervical spine is theoretically of great benefit to the schoolboy rugby players.

Kaigle et al (1997) showed that in the lumbar spine hypermobility, with one vertebra “slipping” on the next, does not seem to occur, but that the motion pattern is greatly altered. This trend was also found in the results of this investigation. Initial mean angle of flexion however changed from being held in extension by 1.857° at the C6/C7 motion segment to 0.796° of flexion at the C5/C6 level to 4.567° at the C4/C5 level. The strain on the posterior fibres of the annulus fibrosus of the C4/C5 level could be greatly increased. It could therefore be theorised that the altered motion found by Kaigle et al (1997) could also apply to the schoolboy rugby players with biomechanical dysfunction of their cervical spines. Altered motion results in changes in length and loading of the ligaments and this may again result in altered firing

patterns and changes in the coordination patterns of the muscles. The consequence of this to the schoolboy rugby player could be devastating if the motion segments do not respond optimally during a high risk situation such as a tackle. This situation was improved by the correction technique, with the second mean angles suggesting less strain of the posterior annulus fibrosus of the disc.

7.3.5 Effect sizes (d-values) for the various x-ray measurements for Group 1 Before and After Manual Physiotherapy Treatment

The physiotherapy technique was found to be highly significant in correcting biomechanical dysfunction of the cervical spine when comparing x-ray measurements before and after manual physiotherapy treatment. Figure 7.5 illustrates the various effect sizes, with d-values, for the various x-ray measurements namely, flexion, extension, angles of rotation and translation, of Group 1. The physiotherapy evaluation technique suggested that the motion segments of the lower cervical spine were held in extension and this was confirmed by the x-ray findings.

Flexion improved significantly for C5/C6 ($d = 0.996$) and C6/C7 ($d = 2.189$) as well as for total flexion ($d = 1.885$) of the cervical spine and moderately for the C3/C4 ($d = 0.433$) and C4/C5 ($d = 0.596$) levels (Figure 7.5). The angles of rotation for the C5/C6 ($d = 0.961$) and C6/C7 ($d = 1.124$) also showed high statistically significant improvement. The remaining translation and extension measurements only changed with small significance, as was expected since the physiotherapy evaluation did not find any extension restrictions in the rugby players.

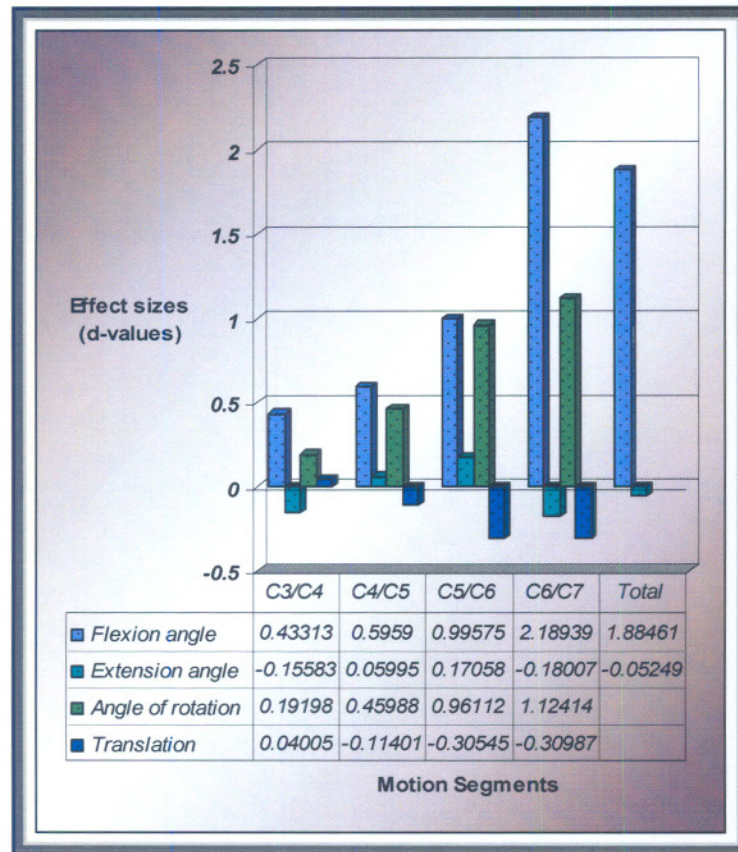


Figure 7.5: Effect sizes (d-values) for the various x-ray measurements performed on the motion segments of the cervical spine before and after manual physiotherapy treatment of Group 1.

This is a very significant finding for physiotherapists, since no literature could be found to prove the effectiveness of this specific manual physiotherapy technique. These results could therefore be used by physiotherapists to compare results of future studies and to form an idea on the improvement that could be expected in patients when this treatment technique is used.

The flexion gained by this physiotherapy technique was not associated with a corresponding reduction in the extension component of the motion, therefore indicating a normalisation of the movement from flexion to extension. No subsequent different biomechanical dysfunction was caused by this treatment technique. This is confirmed by the significant improvement in the angle of rotation for the motion segments mostly affected, namely C5/C6 and C6/C7.

For the physiotherapy profession these findings are of great relevance and importance. In the event of biomechanical dysfunction found in any patient who may be referred for physiotherapy treatment, this provides a technique that could be used to correct the found dysfunction. Correction of dysfunction would then normalise the strain on the particular motion segment and with strengthening of the muscles around the cervical spine the patient will have a more functional neck. This could be beneficial both in the prevention as well as for the treatment of neck pain and disability. The value for the schoolboy rugby player will be discussed later (Chapter 7:278,280).

In the following section the results of the therapeutic exercise programme for the correction of biomechanical dysfunction, as performed by Groups 2 and 3, will be stated and discussed.

7.4 Groups 2 and 3. Therapeutic Exercise Programme for the Correction of Biomechanical Dysfunction

This section includes the results and discussion of the efficacy and safety of the therapeutic exercise programme for the correction of biomechanical dysfunction. The programme was performed by players with (Group 2) and without (Group 3) biomechanical dysfunction of their cervical spines according to the physiotherapy evaluation technique described earlier (Chapter 6:170). The players without biomechanical dysfunction performed the programme to test its safety. This is of vital importance before a decision is taken to implement the programme for schoolboy rugby players who did not receive physiotherapy evaluation before commencing with the therapeutic exercise programme. The programme was developed using the basic principle of physiotherapy techniques used for the correction of biomechanical dysfunction for the Group 1 players. The programme was performed for a month with x-rays taken before and after the programme.

7.4.1 Testing the Effectiveness of the Therapeutic Exercise Programme performed by Group 2

The effectiveness of the therapeutic exercise programme for the correction of biomechanical dysfunction was determined by the results of the 25 players with biomechanical dysfunction of their cervical spines that performed the programme and was part of Group 2. The flexion results will be given first, followed by the extension, angles of rotation and translation results.

7.4.1.1 Results for Flexion angles measured for Group 2

As for Group 1 the biomechanical dysfunction most commonly found for the Group 2 players, using the physiotherapy evaluation technique was flexion restriction of the C5/C6 and C6/C7 motion segments. This was confirmed by the x-ray measurements with mean flexion angles of less than 4° before initiating the therapeutic exercise programme. The results for all the flexion angles measured on x-ray are given in Table 7.6 and Figure 7.6. Note that the mean flexion angles for the C5/C6 and C6/C7 motion segments are restricted, but not as severely as the restriction found in Group 1. The flexion angles for the C5/C6 ($d = 0.43$), C6/C7 ($d = 0.685$) and total flexion ($d = 0.46$) improved with moderate significance.

Table 7.6: Results of the flexion angles for Group 2, before and after the therapeutic exercise programme.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	-6.06	3.53	-7.02	3.39	0.280
C4/C5	-5.98	4.81	-6.60	3.08	0.147
C5/C6	-3.99	5.00	-5.86	4.07	0.430
C6/C7	-1.36	4.68	-4.92	3.12	0.685
Total Flexion	-17.95	12.29	-23.82	8.63	0.460

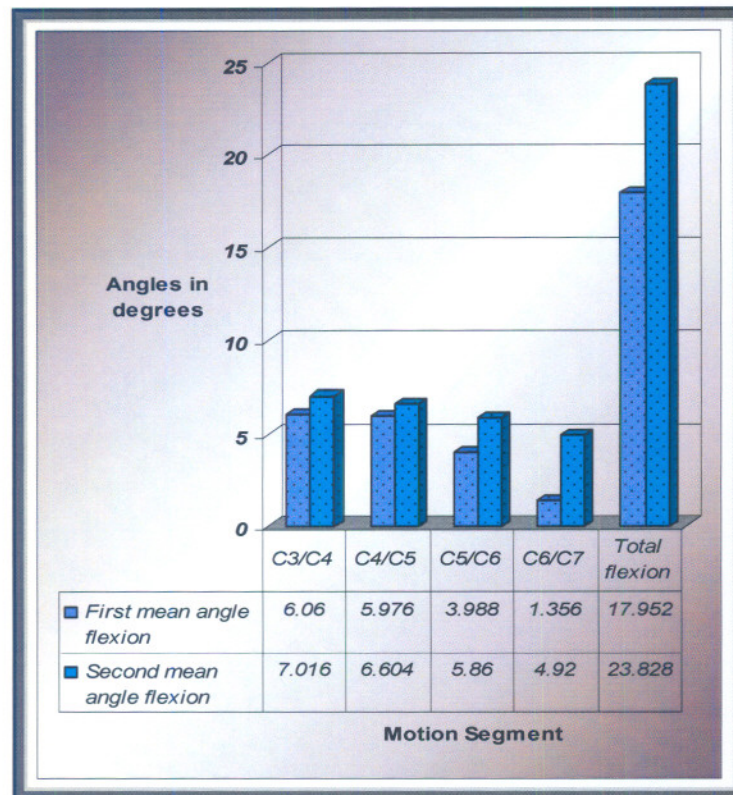


Figure 7.6: Results of the flexion angles for Group 2, before and after the therapeutic exercise programme.

The improvement in flexion restriction of the motion segments after the therapeutic exercise programme was not as significant as the results of the manual physiotherapy technique. A possible explanation for this could be that the initial flexion restriction was not as severe, initial mean total flexion for Group 1 -9.56° compared to -17.95° for Group 2, and therefore the opportunity for improvement was accordingly less. The improvement was however still small to moderately significant and therefore it could be suggested that all rugby players with flexion restriction of their cervical spines could benefit from this therapeutic exercise programme.

7.4.1.2 Results for Extension X-ray measurements for Group 2

The extension movement of all the players tested by the physiotherapy technique were found to be unrestricted and this was confirmed with the extension x-ray measurements. There were small significant changes in the mean extension angles for

the C3/C4 ($d = 0.155$), C4/C5 ($d = 0.033$) and C5/C6 ($d = -0.007$) motion segments measured before and after the therapeutic exercise programme (Table 7.7 and Figure 7.7). For the C6/C7 motion segment the mean extension angle increased with small significance ($d = 0.318$).

Table 7.7: Results for extension angles for Group 2 before and after completing the therapeutic exercise programme.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	8.30	3.58	8.70	3.02	0.155
C4/C5	9.77	4.14	9.90	3.87	0.033
C5/C6	10.07	3.83	10.04	3.51	-0.007
C6/C7	8.53	4.56	10.27	4.13	0.318
Total Extension	36.67	8.87	38.91	8.60	0.274

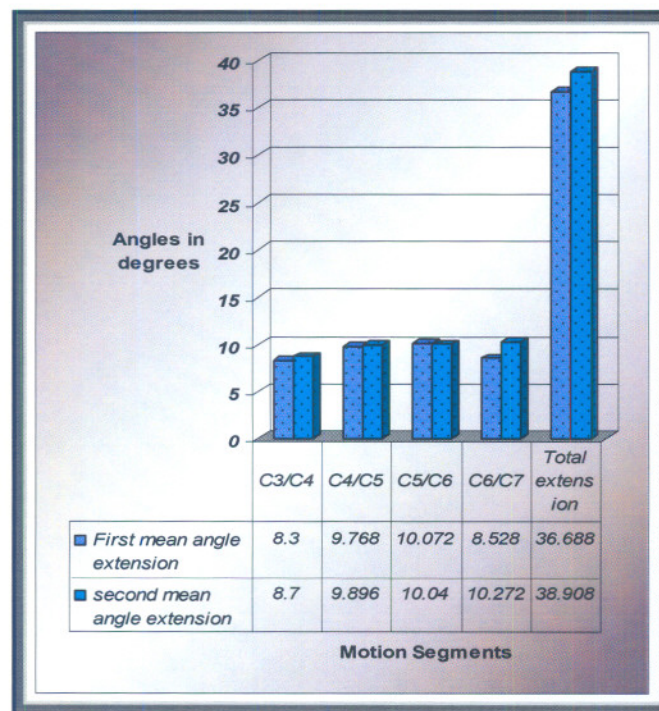


Figure 7.7: Results for extension angles for Group 2 before and after completing the therapeutic exercise programme.

The results for the extension angle measurements corresponded well to the results found for the players of Group 1. Therefore it could also be concluded that the cervical spines of the Group 2 players functioned well biomechanically during neck extension. The mean extension angles also did not decrease with highly statistical significance, therefore it could be assumed that the therapeutic exercise programme did not cause any extension restriction to occur, with a small to moderate significant improvement found in the flexion angles.

7.4.1.3 Results for Angles of Rotation X-ray measurements for Group 2

The angles of rotation for the various motion segments were calculated as already explained. The only moderately significant result was found for the C6/C7 motion segment ($d = 0.616$). This result was to be expected since the other motion segments were close to the norm with the start of the programme. The results are illustrated in Table 7.8 and Figure 7.8.

Table 7.8: Results for the angles of rotation x-ray measurements for Group 2 before and after completing the therapeutic exercise programme.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	14.36	3.22	15.72	3.17	0.358
C4/C5	15.74	5.35	16.50	4.31	0.146
C5/C6	14.06	4.98	15.90	4.74	0.337
C6/C7	10.46	5.73	14.62	4.44	0.616

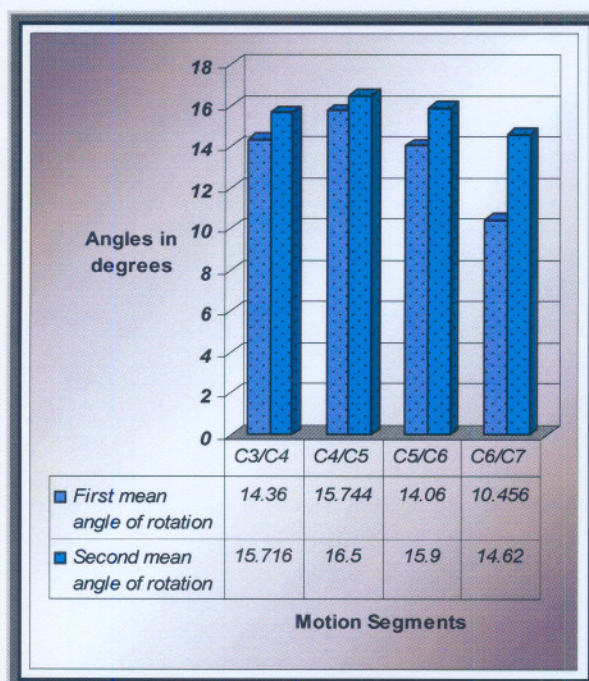


Figure 7.8: Results for the angles of rotation x-ray measurements for Group 2 before and after completing the therapeutic exercise programme.

The fact that the angle of rotation for the C6/C7 motion segment increased to a more normal value could, as concluded for the Group 1 players, be interpreted as a more functional motion segment. An improvement in the angle of rotation implies more range of motion for the motion segment for the movement of extension to flexion. Restricted range of motion, as found with smaller restricted angles of rotation, could predispose a schoolboy rugby player to cervical spine injury due to the fact that the normal biomechanical function of the cervical spine is restricted. This increase in mobility of the motion segments could contribute positively to the biomechanical function of the entire cervical spine.

7.4.1.4 Results of the Translation X-ray measurements for Group 2

Translation of the superior vertebra on the inferior vertebra of the motion segments was measured for the players of Group 2. Small statistically significant changes in the distance of translation were found between the first and the second measurements.

The translation was measured in standard units by the radiographic software program (Chapter 6:180). The results of the translation measurements are stated in Table 7.9 and Figure 7.9.

Table 7.9: Results of the translation x-ray measurements for Group 2 before and after completing the therapeutic exercise programme.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	14.06	7.55	13.53	5.92	-0.091
C4/C5	10.78	6.53	10.83	5.27	0.008
C5/C6	11.99	6.60	12.03	6.54	0.006
C6/C7	8.38	6.23	7.93	5.25	-0.100

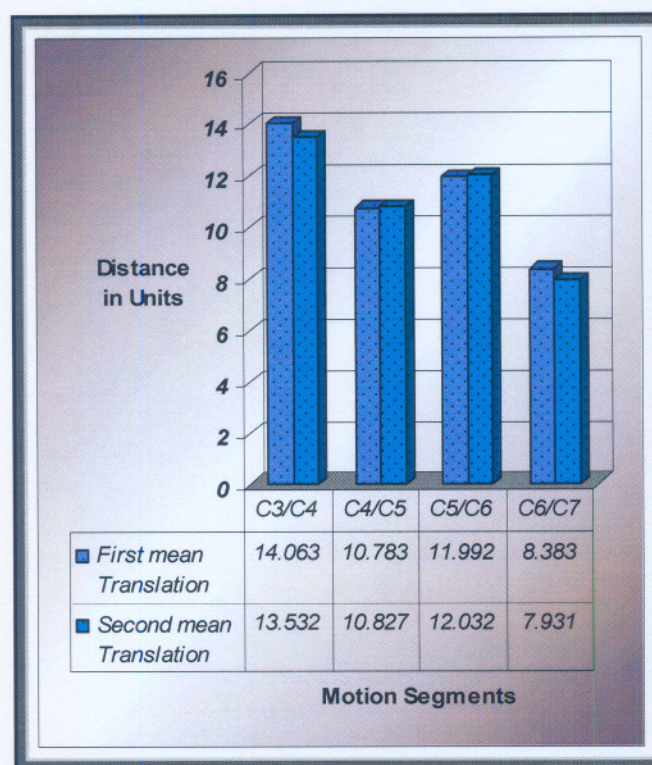


Figure 7.9: Results of the translation x-ray measurements for Group 2 before and after completing the therapeutic exercise programme.

As explained during the results of translation for Group 1, the fact that very small changes in translation could be seen is an indication that the strain on posterior fibres of the annulus fibrosus of the intervertebral disc of the C4/C5 motion segment is increased due to the large difference in flexion angles between C4/C5 and C5/C6. This difference is corrected following the therapeutic exercise programme, which reduces the strain on the C4/C5 motion segment. Accordingly the negative trend seen in the translation measurements are considered as an improvement, even if not of moderate to high statistical significance.

7.4.1.5 Effect sizes (d-values) for the various x-ray measurements for Group 2 Following the Completion of the Therapeutic Exercise Programme

The results following the therapeutic exercise programme enforced the evidence that the therapeutic exercise programme is effective in the correction of biomechanical dysfunction with moderate statistical significance. The following measurements were found to improve with moderate practical significance namely C5/C6 flexion ($d = 0.431$) and C6/C7 flexion ($d = 0.685$) as well as a moderate significant improvement for total flexion ($d = 0.46$). The angle of rotation for the C6/C7 motion segment also improved with moderate significance ($d = 0.615$). The remaining measurements demonstrated small significant changes. The effect sizes (d-values) for all the measurements are provided in Figure 7.10.

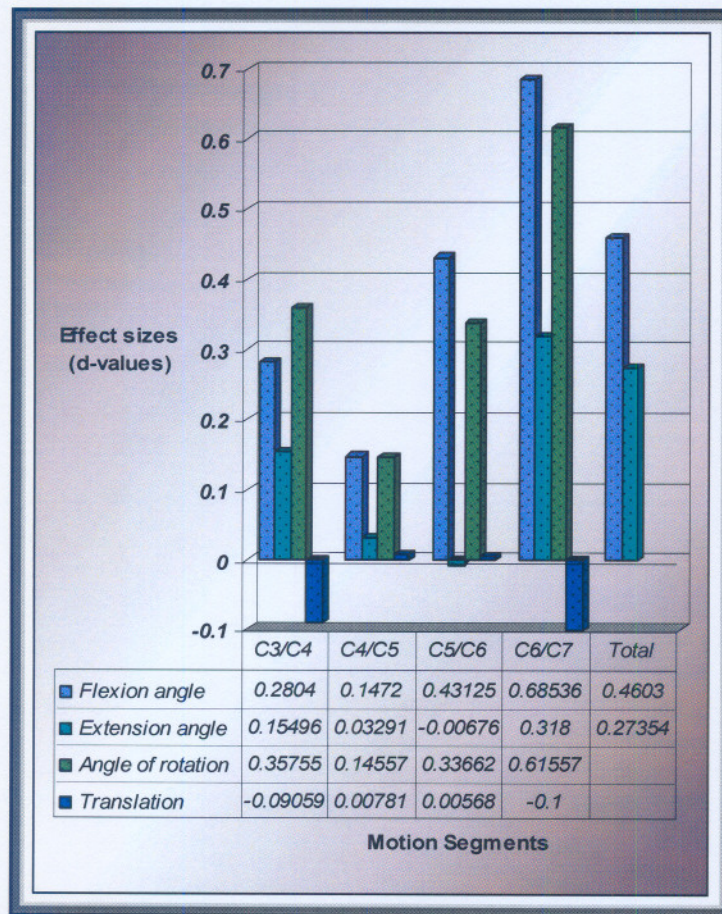


Figure 7.10: Effect sizes (d-values) for the various x-ray measurements performed before and after the therapeutic exercise programme for Group 2.

These results indicate that the therapeutic exercise programme is effective in the correction of the cervical spine dysfunction, but to a lesser degree than the manual physiotherapy technique used for the players of Group 1. The mean flexion angles following the second sets of x-rays were however very similar for the players of Groups 1 and 2 with mean total flexion angle following the second set of x-rays of -24.44° and -23.83° for Groups 1 and 2 respectively. It thus proves the notion that this therapeutic exercise programme is effective for the correction of cervical biomechanical dysfunction in schoolboy rugby players.

7.4.2 Group 3. Testing the Safety of the Therapeutic Exercise Programme

This programme was also performed by 25 players who did not present with biomechanical dysfunction of their cervical spines, as evaluated using the manual physiotherapy technique validated in the previous chapter (Chapter 6:169). The results for the x-ray measurements viz. flexion angles, extension angles, angles of rotation and translation will be given hereafter.

7.4.2.1 Results of the flexion x-ray measurements for Group 3

No flexion restrictions, using the validated physiotherapy evaluation technique, were found for the players included in Group 3. This was confirmed by the x-ray measurement findings. The following mean flexion angles are the results for Group 3 (Table 7.10 and Figure 7.11). The only small statistically significant finding was the improvement in flexion angle of the C6/C7 motion segment with an effect size of $d = 0.385$. The changes in flexion angles for the other motion segments as well as total flexion were of very small significance.

Table 7.10: Results of the flexion x-ray measurements for Group 3 before and after the therapeutic exercise programme.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	-6.14	3.14	-6.70	2.73	0.161
C4/C5	-6.95	3.64	-6.23	3.36	-0.170
C5/C6	-5.58	4.71	-5.01	4.19	-0.097
C6/C7	-1.78	5.18	-4.38	4.01	0.385
Total Flexion	-20.46	11.22	-22.32	9.77	0.131

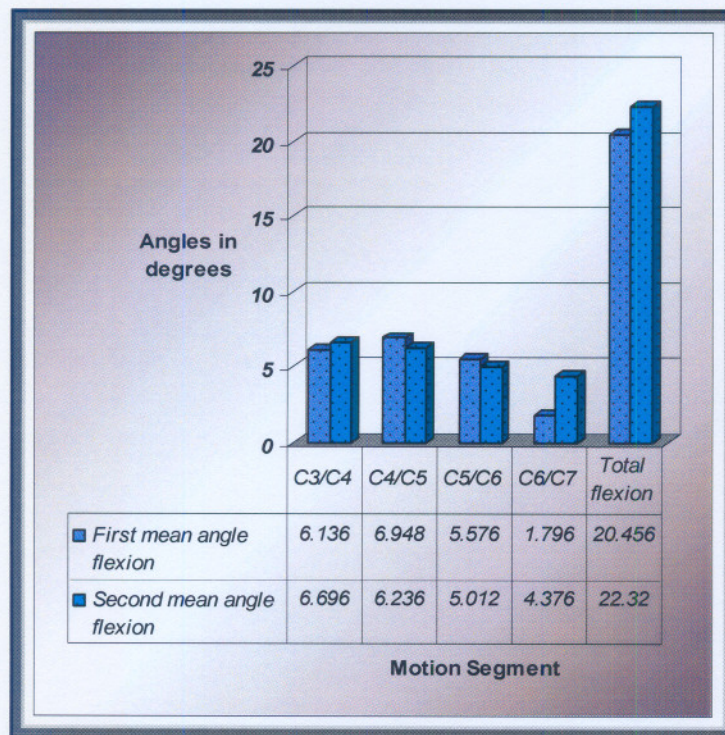


Figure 7.11: Results of the flexion x-ray measurements for Group 3 before and after the therapeutic exercise programme.

The mean flexion angles for most of the motion segments did not change significantly, except for the small improvement of the C6/C7 motion segment and this indicates that the therapeutic exercise programme is safe for flexion angles.

7.4.2.2 Results of the Extension X-ray measurements for Group 3

No extension restrictions were found in any of the players included in Group 3. This was confirmed with the x-ray measurement findings. A small significant change in the mean extension angles for the C6/C7 ($d = 0.073$) motion segment as well as for total extension ($d = 0.077$) were found (Table 7.11 and Figure 7.12).

Table 7.11: The results of the mean extension angles for Group 3 before and after completing the therapeutic exercise programme.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	7.67	2.87	6.83	2.49	-0.262
C4/C5	9.52	3.26	11.28	3.31	0.389
C5/C6	9.68	3.57	10.76	3.48	0.209
C6/C7	8.83	5.45	9.40	4.84	0.073
Total Extension	35.71	9.63	36.61	8.58	0.077

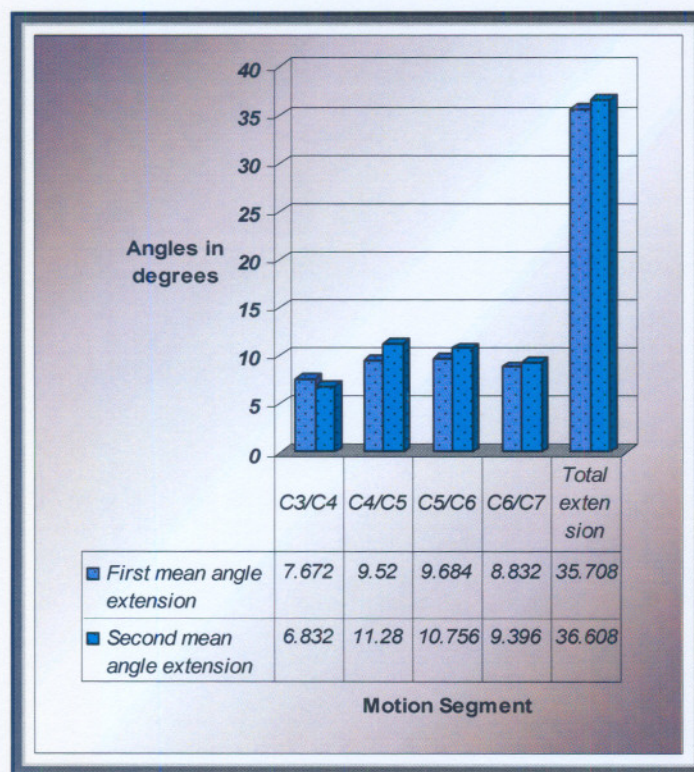


Figure 7.12: The results of the mean extension angles for Group 3 before and after completing the therapeutic exercise programme.

The results of the extension angles suggest that the therapeutic exercise programme is safe to be performed by players without biomechanical dysfunction of their cervical

spines since none of the motion segments showed a moderate to high statistically significant change in mean extension angles.

7.4.2.3 Results for the Angles of Rotation X-ray measurements for Group 3

The angles of rotation for the Group 3 were calculated in the same way as for Group 1 and 2, as detailed in the previous (Chapter 6:178). A small statistically significant improvement was found in the angle of rotation for the C6/C7 motion segment ($d = 0.346$). The remainder of the motion segments also showed small significant changes for the mean angles of rotation. The results of the calculated angles of rotation are provided in Table 7.12 and Figure 7.13.

Table 7.12: The results of the mean angles of rotation for Group 3 before and after completing the therapeutic exercise programme.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	13.81	3.61	13.53	4.44	-0.062
C4/C5	16.47	5.03	17.52	4.69	0.210
C5/C6	15.26	5.90	14.11	4.84	-0.167
C6/C7	10.63	6.59	13.77	5.06	0.346

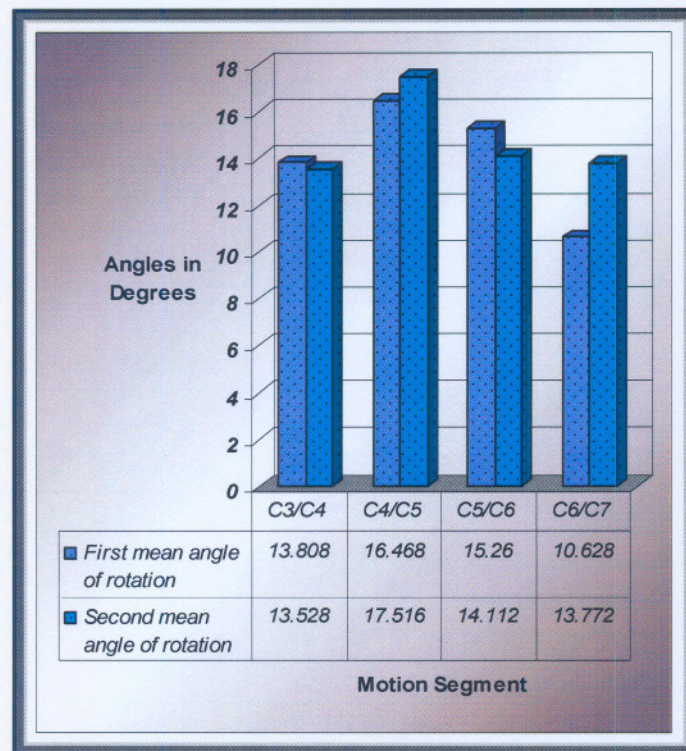


Figure 7.13: The results of the mean angles of rotation for Group 3 before and after completing the therapeutic exercise programme.

Since none of the motion segments measured showed an adverse effect of moderate to high statistical significance as far as the angles of rotation measurements is concerned, it could be assumed that the therapeutic exercise programme could be performed by all players without biomechanical dysfunction as far as angles of rotation is concerned.

7.4.2.4 Results for the translation x-ray measurements for Group 3

The changes in translation measurements for Group 3 were of very small statistical significance for all the motion segments with d-values of less than 0.2 for all the motion segments measured. This is illustrated in Table 7.13 and Figure 7.14.

Table 7.13: Results for the mean translation x-ray measurements for the Group 3 before and after the therapeutic exercise programme.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	12.96	5.79	14.13	5.82	0.152
C4/C5	9.29	5.87	9.74	4.69	0.059
C5/C6	7.56	6.77	7.99	6.57	0.050
C6/C7	6.57	5.62	5.70	5.47	-0.137

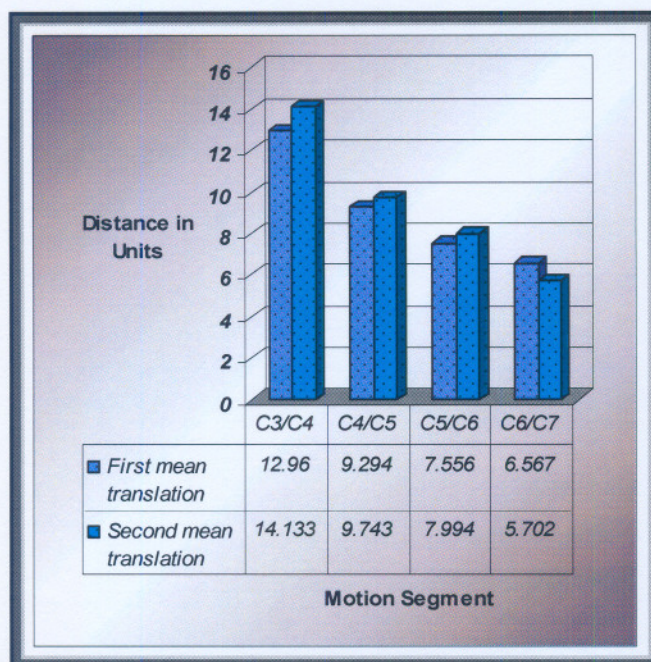


Figure 7.14: Results for the mean translation x-ray measurements for the Group 3 before and after the therapeutic exercise programme.

The insignificant changes in the translation measurements for the Group 3 players could be interpreted as the motion segments remaining stable after the therapeutic exercise programme. A significant increase in the mean translation measurements of the motion segments could have been theorised as causing a laxity, and therefore hypermobility of the motion segment, rendering them unstable. These results confirm that the therapeutic exercise programme does not cause an increase in translation and

therefore this programme is safe for players without biomechanical dysfunction of their cervical spines.

7.4.2.5 Effect sizes (d-values) for the various Motion Segment X-ray measurements performed for Group 3 before and after the Therapeutic Exercise Programme.

The therapeutic exercise programme for the correction of biomechanical dysfunction was found to be very safe with only a small statistically significant improvement in the mean flexion angle as well as the angle of rotation for the C6/C7 motion segment being found with effect sizes of $d = 0.385$ and $d = 0.346$ respectively. The remainder of the measurements were statistically of very small significance. The effect sizes (d-values) for all the measurements are given in Figure 7.15.

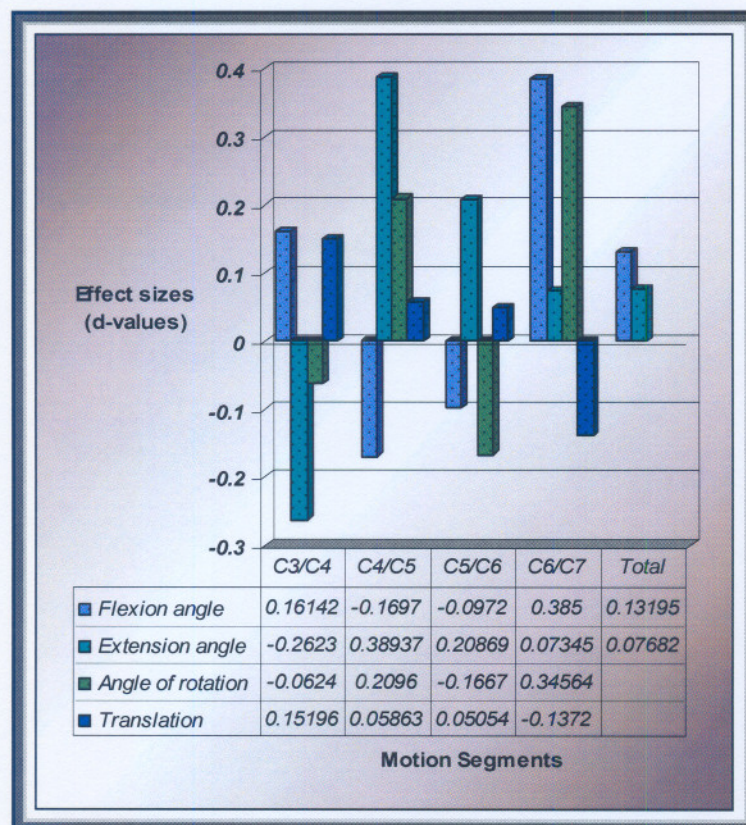


Figure 7.15: Effect sizes (d-values) for all the x-ray measurements for Group 3.

The mean flexion angles found in Groups 2 and 3 appear to be very similar, except for the C5/C6 motion segment which was found to be less for Group 2 than Group 3. This could be explained by the greater accuracy in the physiotherapy evaluation technique for the C5/C6 motion segment (Chapter 6:170) as found during the validation of the manual physiotherapy evaluation technique.

The results provided for Group 2 and Group 3 indicates that the therapeutic exercise programme for the correction of biomechanical dysfunction is both effective in correcting biomechanical dysfunction as well as safe for those players without dysfunction. This programme could thus be implemented for all schoolboy rugby players without physiotherapy evaluation or x-rays to test for possible dysfunction.

7.5 Group 4. Results for the Control Group

The control group initially consisted of 25 subjects, but two subjects dropped out after sustaining whiplash injuries in a motor vehicle accident. This group consisted of players with or without cervical biomechanical dysfunction. They received no intervention and participated in rugby for the period between the first and the second x-rays. They were asked not to change their normal training programme during the period of the clinical trial.

7.5.1 Results of the Flexion angle X-ray Measurements for Group 4

The results of the flexion measurement for the first and the second sets of x-rays are given in Table 7.14 and Figure 7.16. Note the slight deterioration in the mean flexion angle for the C4/C5 ($d = -0.206$) and C5/C6 ($d = -0.255$) motion segments during the period between the first and the second sets of x-rays. The total flexion of the motion segments measured also deteriorated from -20.44° to -18.05° .

Table 7.14: The results of the mean flexion angles for the first and second sets of x-rays for Group 4.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	-6.17	6.18	-5.69	4.43	-0.119
C4/C5	-6.93	4.78	-6.03	4.87	-0.206
C5/C6	-5.30	5.87	-3.93	5.70	-0.255
C6/C7	-2.039	5.10	-2.15	4.023	0.018
Total Flexion	-20.44	14.4	-18.05	12.74	-0.183

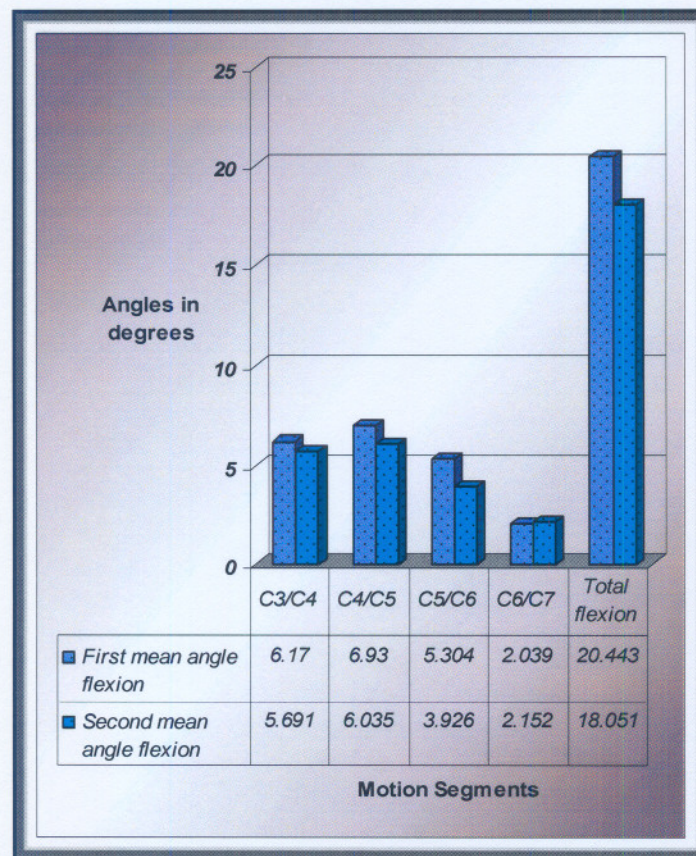


Figure 7.16: The results of the mean flexion angles for the first and second sets of x-rays for Group 4.

Even though the change in the flexion angles for C4/C5 and C5/C6 is of small statistical significance, the negative trend seen in the total flexion of the measured motion segments is of clinical significance. These players did not maintain their flexion movement throughout the rugby season. A restriction in flexion angles is associated with biomechanical dysfunction of the cervical spine therefore it could be concluded that the biomechanical dysfunction of the rugby players either started or the dysfunction worsened during the rugby season. It is therefore necessary to correct biomechanical dysfunction in rugby players as early as possible and to maintain this correction for as long the players participate in the game of rugby.

7.5.2 Results of the mean Extension angles for Group 4, the control group.

The results of the extension angles measured between the first and the second sets of x-rays are given in Table 7.15 and Figure 7.17. The changes in the angles of extension were of small statistical significance with d-values ranging between -0.173 and 0.227.

Table 7.15: Results of the extension angles measured on x-rays for Group 4.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	9.14	4.92	8.06	3.67	-0.240
C4/C5	9.52	4.37	10.06	3.93	0.173
C5/C6	11.46	8.86	11.46	4.05	0.141
C6/C7	11.24	3.96	10.39	4.86	-0.159
Total Extension	41.35	10.01	39.53	9.43	-0.227

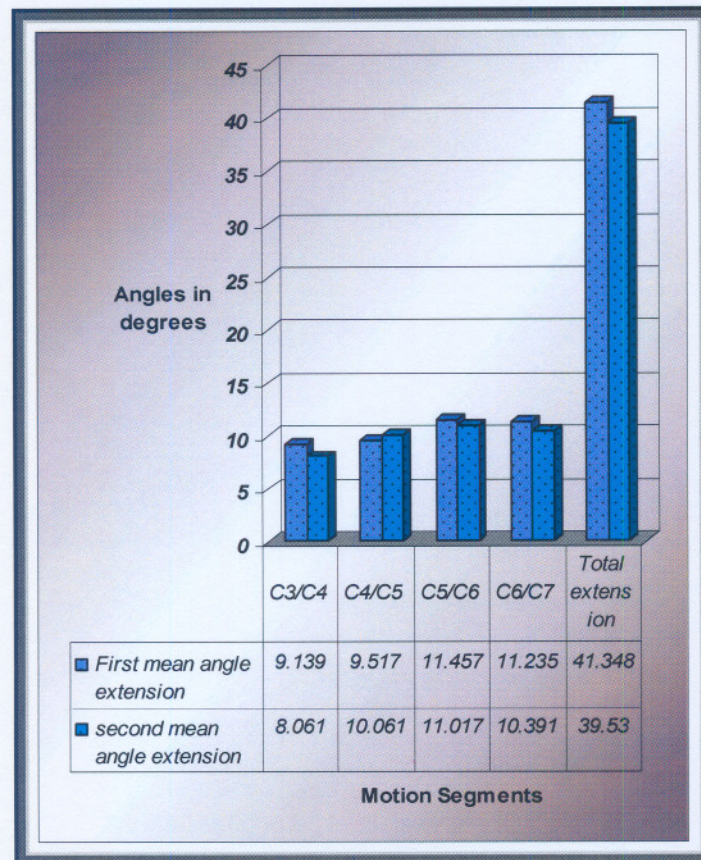


Figure 7.17: Results of the extension angles measured on x-rays for Group 4.

The trend of the extension angles seen for Group 4 (control group) also seemed to show a negative trend, even if the statistical significance was only small. This negative trend could be interpreted as deterioration in range of motion of the cervical spine, which could influence the function of the cervical spine negatively (Chapter 5:156).

7.5.3 Results of the Angles of Rotation for Group 4

The results of the angles of rotation calculated for all the motion segments indicate a small significant negative change with d-values of between $d = -0.075$ for the C4/C5 motion segment and $d = -0.246$ for the C3/C4 motion segment (Table 7.16 and Figure 7.18).

Table 7.16: Results of the angles of rotation for the first and second sets of x-rays for Group 4.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	15.31	6.18	13.75	4.87	-0.246
C4/C5	16.45	5.41	16.10	5.65	-0.075
C5/C6	16.76	6.3	15.19	6.98	-0.241
C6/C7	13.27	6.21	12.54	5.35	-0.099

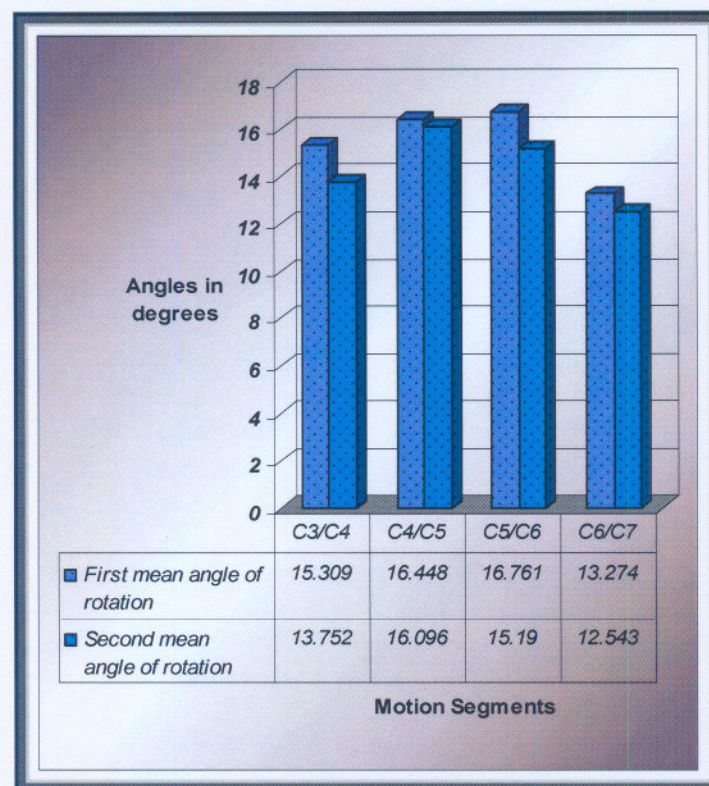


Figure 7.18: Results of the angles of rotation for the first and second sets of X-rays for Group 4.

The results of the angles of rotation found for the control group follows the negative trend seen in the flexion angles extension angles. This support the theory that biomechanical dysfunction could deteriorate while participating in the game of rugby.

7.5.4 Results of the Translation Measurements for Group 4

The results of the translation measurements for the first and second sets of x-rays are illustrated in Table 7.17 and Figure 7.19. Note that the negative trends seen for the other x-ray results are also seen for the translation measurements with a decrease in translation. These results are of very small statistical significance with d-values ranging between $d = -0.042$ and $d = 0.001$.

Table 7.17: Results of the translation measurements for Group 4.

Motion segment	Mean 1st X-ray	Std Dev	Mean 2nd X-ray	Std Dev	d-value
C3/C4	14.36	9.99	13.54	9.88	-0.130
C4/C5	10.95	4.37	10.45	5.41	-0.042
C5/C6	10.88	9.26	10.32	8.86	-0.080
C6/C7	9.67	6.98	9.68	7.84	0.001

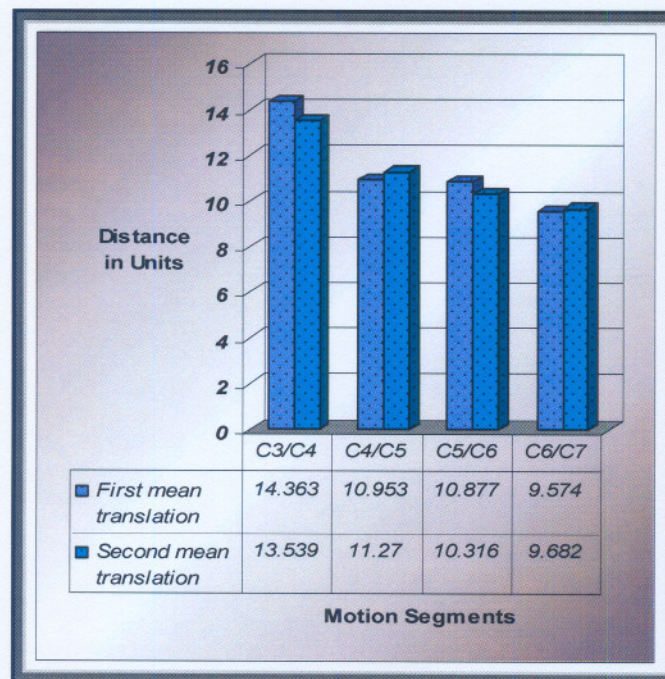


Figure 7.19: Results of the translation measurements for Group 4.

The negative trend in x-ray measurements detected for flexion and extension angles as well as for the angles of rotation was also seen for the mean translation measurements between the first and the second x-rays. This strengthens the theory further that continued participation in rugby causes biomechanical dysfunction or a worsening of already present biomechanical dysfunction.

7.5.5 Effect sizes (d-values) for all the Motion Segment X-ray Measurements of Group 4

The results of the various x-ray measurements for the first and the second sets of x-rays show a negative trend of small statistical significance. The only result that was of small statistical significance was the deterioration in mean flexion angles of the C4/C5 and C5/C6 motion segments as well as a deterioration of small statistical significance in the angle of rotation of the C5/C6 motion segment. The effect sizes (d-values) of the various x-ray measurements are given in Figure 7.20

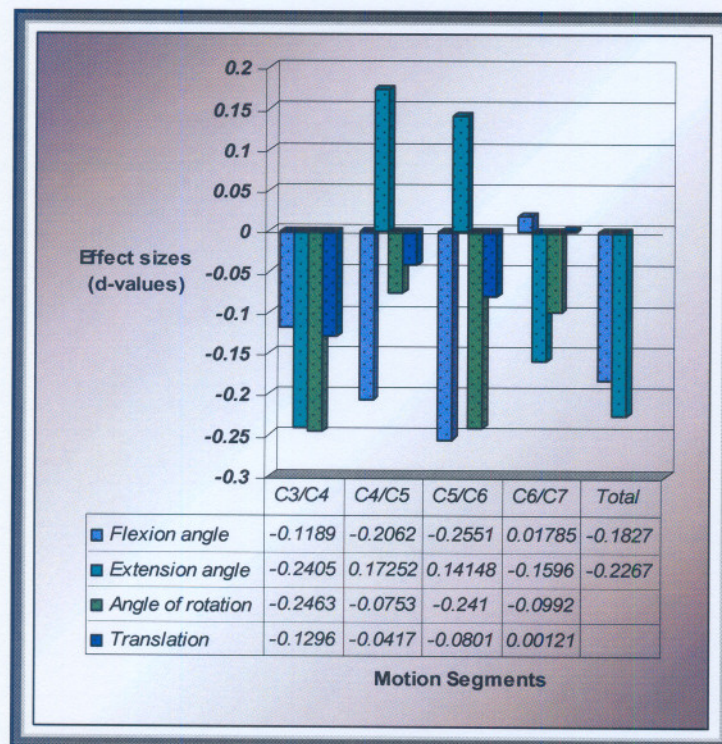


Figure 7.20: Results of the effect sizes (d-values) for Group 4.

The negative trend of the x-ray measurements for flexion and extension angles, the angles of rotation as well as the translation measurements is clearly illustrated in Figure 7.20. The implication of this negative trend, even if the results are of small statistical significance, is extremely important for the schoolboy rugby player since this is an indication that for every rugby season the player participates in the game of rugby his cervical spine movement deteriorates and the biomechanical dysfunction of his cervical spine progresses. This trend has not been documented in the literature before and therefore the importance of implementing some form of intervention programme for the correction of biomechanical dysfunction is extremely important. If the biomechanical dysfunction is not corrected it will worsen during each rugby playing season of the player.

7.6 Testing the Neck Rehabilitation Programme

The following section will provide the results of the rehabilitation programme followed by the subjects of Groups 1, 2 and 3. All the players from Groups 1, 2 and 3 started with this programme after the second set of x-rays. The aim of the programme was to maintain the correction in biomechanical dysfunction following the various interventions and to rehabilitate the neck in this corrected position. The programme included various elements necessary for a complete rehabilitation programme (Chapter 4:88). The element of strength was tested by objectively measuring cervical circumference before and after the programme. The results for the change in cervical circumference measurements will be given first followed by the x-ray measurements of the second and the third sets of x-rays.

The results for the players who completed the neck rehabilitation programme were analysed according to compliance. It was theorised that the players with better compliance will have better results. Firstly the results of the players who completed the programme, without taking their compliance into account, were analysed. Secondly the results of the players who objectively complied with the programme will be given. Objective compliance could be described as the players who, according to the weekly telephonic questioning of the players, either complied fully or partially with the rehabilitation programme. The third analysis was performed on the group of

players who subjectively complied with the rehabilitation programme. The players had to answer “yes” or “no” to a question on whether they completed their programme regularly in the final questionnaire. The subjects who answered “yes”, was considered as having subjectively complied with the rehabilitation programme.

The subjects who did not perform the programme at all were excluded from these results. A large number of players did not complete the final rehabilitation programme, due to factors such as injury as well as academic responsibilities. The Grade 12 players did not continue with rugby following the July school break due to academic responsibilities. Of the 75 players of Groups 1, 2 and 3, 47 completed the programme without considering compliance, 38 players objectively complied and 17 subjectively complied with the rehabilitation programme.

7.6.1 Results of Cervical Circumference following the Neck Rehabilitation Programme

The cervical circumference results for the players who completed the neck rehabilitation programme are given according to their compliance groups (Table 7.18). The measurements of cervical circumference are given in centimetres. The improvement in cervical circumference for all three compliance groups is highly statistically significant with d-values ranging between $d = 0.813$ for the players with subjective compliance and $d = 1.033$ for the players with objective compliance (Figure 7.21).

Table 7.18: Cervical circumference results of the various compliance groups for all the players who completed the rehabilitation programme.

Compliance	n	1st mean measurement	Std Dev	2nd mean measurement	Std Dev	d-value
Excluding compliance	47	38.97	2.02	39.89	2.33	1.023
Objective compliance	38	38.90	2.07	39.83	2.61	1.033
Subjective compliance	17	39.57	2.13	40.51	2.34	0.813

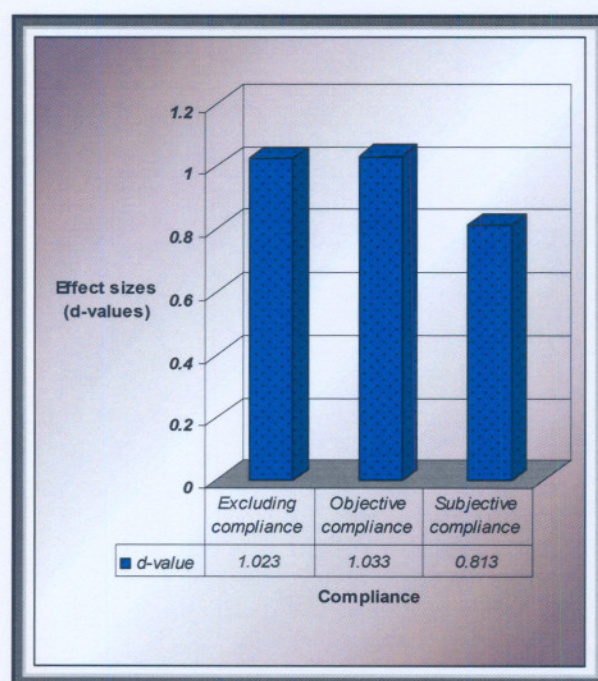


Figure 7.21: Effect sizes (d-values) of the various compliance groups for all the players who completed the neck rehabilitation programme.

The body mass results for the players who completed the neck rehabilitation programme are given in Table 7.19. The various measurements are for the three compliance groups. The measurements of body mass are given in kilograms. These results illustrate a small to moderate significant increase in body mass during the

period that the players participated in the neck rehabilitation programme with effect sizes ranging between $d = 0.283$ and $d = 0.445$.

Table 7.19: Body mass results of the various compliance groups for all the players who completed the rehabilitation programme.

Compliance	n	1st mean measurement	Std Dev	2nd mean measurement	Std Dev	d-value
Excluding compliance	47	80.22	11.57	81.55	11.52	0.445
Objective compliance	38	80.27	12.42	81.49	12.08	0.427
Subjective compliance	17	83.64	13.19	84.39	12.06	0.283

As stated in the literature review (Chapter 4:88), many authors propose strengthening of the neck muscles in the prevention of cervical spinal cord injury. Scher (1991) studied x-rays of the cervical spines of people carrying extremely heavy loads on their head in the rural areas of South Africa. He concluded that no degenerative changes could be seen in their cervical spines and suggested that this could be due to the strong stabilising ability of their neck muscles. He suggested that rugby players should improve their strength and stability in the same way to stabilise their cervical spines and that the cervical circumference of the neck should be used to test any proposed rehabilitation programme.

All the players who completed the rehabilitation programme showed a highly statistically significant improvement in cervical circumference, irrespective of the degree of compliance with the rehabilitation programme. The reason for this significant increase in cervical circumference could not be the results of an increase in body mass since the increase in body mass for the same period was only of small to moderate significance (Table 7.18 and 7.19).

A possible explanation for why compliance to the rehabilitation did not seem to alter the results dramatically could be the following. During phase one of the rehabilitation programme various normal movement patterns of the cervical spine were included as

well as emphasis on core stability, stabilisation, balance, and stretching. The players learned the correct motor patterns for cervical spine movement and formed engrams for these patterns in their memories. This could have resulted in them using their necks more appropriately during training, with a subsequent improvement in muscle recruitment of the neck muscles.

Movement is important for spinal health and therefore any exercise programme that trains the spine in a static fashion should therefore be questioned. Many of the neck exercises currently used by schoolboy rugby players include static isometric exercises with the neck in the neutral position. In the questionnaire completed by the players before the start of the interventions, they had to describe the neck strengthening exercises they performed for rugby. Of the 44 players who completed this question 23 stated that they performed some sort of resisted, static, isometric type of exercises. The other 21 players described poor exercises such as rolling the neck from side to side. Two players also competed in wrestling and stated that performed their wrestling exercises, which included dynamic strengthening as well as weight bearing, closed kinetic chain exercises. Fifteen percent of the players who completed the questionnaire did not perform neck exercises of any kind and only 10 % of players stated that performed more than 10 minutes on neck exercises per session.

Initially the researcher hypothesised that the biomechanical dysfunction should be corrected with the physiotherapy intervention and the therapeutic exercise programme for the correction of biomechanical dysfunction followed during the first month of the study. It was further hypothesised that the neck rehabilitation programme will then maintain this correction. The results did not support this hypothesis. A further improvement in the cervical biomechanical dysfunction, still present following the second set of x-rays, was found following the rehabilitation programme. The following section will present and discuss this improvement.

7.6.2 Results of X-ray Measurements following the Neck Rehabilitation Programme

The results of the x-ray measurements of the players who completed the neck rehabilitation programme will be given and discussed in the following section. To visually compare the results between the various compliance groups the motion segments of the cervical spine will be given separately and after all the motion segments a discussion of the results will be done. The flexion results will be given first.

7.6.2.1 Flexion angle Results following the Rehabilitation Programme

The results of the various motion segments will be given in Tables 7.20 to 7.24, starting with the C6/C7 motion segment. The improvement in flexion angle of the C6/C7 motion segment was of moderate significance for all the compliance groups (Table 7.20).

Table 7.20: Results of the flexion angles for the C6/C7 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	-4.30	3.40	-6.53	3.04	0.538
Objective compliance	-4.42	3.56	-6.93	2.80	0.620
Subjective compliance	-4.59	3.35	-6.91	2.29	0.635

The results for the C5/C6 motion segments show an improvement of moderate to high statistical significance with d-values of between $d = 0.515$ for all the players excluding compliance and $d = 0.774$ for the players who subjectively complied with the rehabilitation programme (Table 7.21).

Table 7.21: Results of the flexion angles for the C5/C6 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	-4.79	3.87	-7.13	3.55	0.515
Objective compliance	-4.48	3.97	-7.33	3.64	0.596
Subjective compliance	-5.11	2.79	-7.41	3.63	0.774

The results of the flexion angles for the C4/C5 motion segments show an improvement of small significance with effect sizes ranging between $d = 0.207$ for the players without taking compliance into account, and $d = 0.395$ for the players who subjectively complied with the rehabilitation programme (Table 7.22)

Table 7.22: Results of the flexion angles for the C4/C5 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	-5.99	3.25	-7.62	8.18	0.207
Objective compliance	-5.70	3.38	-8.02	8.98	0.272
Subjective compliance	-6.14	2.78	-7.11	2.56	0.395

The results of the flexion angles of the C3/C4 motion segments are given in Table 7.23 Improvements were statistically small for all the compliance groups with players where compliance was not accounted for ($d = 0.086$), players who subjective complied with the rehabilitation programme ($d = 0.181$) and players with objective compliance ($d = -0.346$).

Table 7.23: Results of the flexion angles for the C3/C4 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	-6.71	3.23	-6.99	3.22	0.086
Objective compliance	-6.20	2.99	-6.82	3.19	0.200
Subjective compliance	-7.35	3.31	-7.78	3.42	0.181

The results of total flexion for all the motion segments measured showed improvements that were of moderate significance. Effect sizes ranged between $d = 0.537$ for the group excluding compliance and $d = 0.68$ for the players with subjective compliance with the rehabilitation programme (Table 7.24).

Table 7.24: Results of the total flexion angles for all the motion segment measured before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	-21.79	9.04	-28.28	11.90	0.537
Objective compliance	-20.80	9.48	-29.10	12.31	0.675
Subjective compliance	-23.18	8.73	-29.21	7.24	0.680

Following the improvement in the flexion angles after the manual therapy and therapeutic exercise programme, a further improvement of moderate significance was seen for the C5/C6 and C6/C7 motion segments. These two motion segments throughout the study were seen to be the levels mostly affected in the schoolboy rugby players. The only literature that could be found on cervical spine flexion movement indicated that the amount of flexion for the various motion segments should be approximately equal. Following the rehabilitation programme the flexion

angles for the players who completed the correction of biomechanical interventions as well as the rehabilitation programme were approximately the same (Figure 7.22). Therefore it is suggested that these mean flexion angles be used for normative data for schoolboy rugby players between the ages of 15 and 18 years of age. The negative symbol indicating the direction of movement was negated for the purpose of the graph.

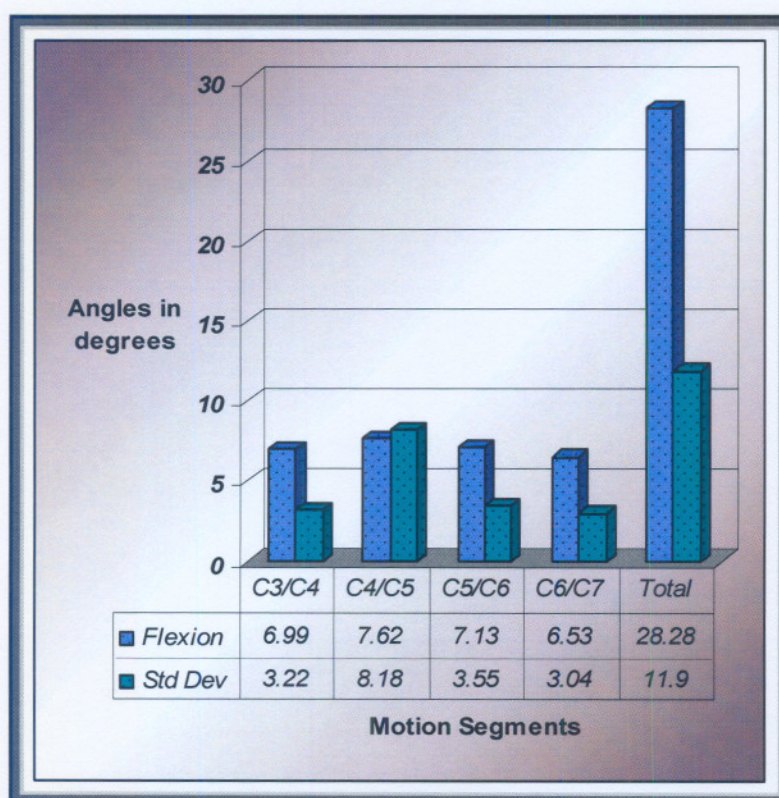


Figure 7.22: Normative flexion angle measurements for cervical spine motion segments C3 to C7 as well as total flexion.

7.6.2.2 Extension angle results following the Rehabilitation programme

The results of the various motion segments will be given in Tables 7.25 to 7.29, starting with the C6/C7 motion segment. A small statistical significant decrease in the

extension angles for all the compliance groups could be seen with effect sizes of between $d = -0.002$ and -0.07 (Table 7.25).

Table 7.25: Results of the extension angles for the C6/C7 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	9.73	5.08	9.73	4.79	0.002
Objective compliance	9.55	4.79	9.83	4.91	0.070
Subjective compliance	9.48	5.97	9.51	5.60	0.009

The results of the extension angles for the C5/C6 motion segment are illustrated in Table 7.26. For these motion segments the improvement in extension angles were of small statistical significance for the group excluding compliance ($d = 0.224$) and the group with objective compliance ($d = 0.197$). The subjective compliance group showed a small significant decrease in extension angles ($d = -0.203$).

Table 7.26: Results of the extension angles for the C5/C6 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	9.99	4.23	11.14	4.75	0.224
Objective compliance	10.29	4.43	11.33	4.58	0.197
Subjective compliance	9.3	4.92	8.34	5.41	-0.203

The extension angles for the C4/C5 motion segment decreased with small significance with effect sizes ranging between $d = -0.301$ and $d = -0.42$ for the group with

subjective compliance and the group where compliance was excluded. These results are illustrated in Table 7.27.

Table 7.27: Results of the extension angles for the C4/C5 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	10.81	3.50	9.33	3.25	-0.420
Objective compliance	10.24	3.22	8.88	2.84	-0.368
Subjective compliance	10.70	3.62	9.45	3.19	-0.301

The results for the C3/C4 motion segments are given in Table 7.28 For this motion segment the mean extension angles improved with small significance with effect sizes ranging from $d = 0.291$ for the group who subjectively complied and $d = 0.371$ for the group excluding compliance.

Table 7.28: Results of the extension angles for the C4/C5 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	7.46	3.04	8.67	2.57	0.371
Objective compliance	7.36	3.3	8.53	2.68	0.346
Subjective compliance	7.63	2.95	8.48	3.04	0.291

The results of the total extension for all the motion segments measured showed a very small improvement for the group where compliance was excluded ($d = 0.128$) and the group who objectively complied ($d = 0.16$). The group who subjectively complied

showed a small significant decrease in total extension with an effect size of $d = -0.237$. These results are illustrated in Table 7.29.

Table 7.29: Results of the total extension angles for all the motion segment measured before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	38	9	38.97	8.26	0.128
Objective compliance	37.44	9.26	38.58	8.44	0.16
Subjective compliance	37.11	10.72	35.77	10.84	-0.237

None of the motion segments or the total extension showed more than a small significant change for the extension angle measurements before and after the neck rehabilitation programme. This is concurrent with the extension measurements results found following the manual therapy and therapeutic exercise programme. These results also confirm the results of the physiotherapy evaluation technique, since no restriction in the extension movement pattern was found for any of the players who performed the neck rehabilitation programme.

No normative values for extension angles were found in the literature. The description for normal extension movement however suggested that extension should be a smooth movement with each motion segment contributing equally to the total movement. The extension angles measured following the third set of x-rays for the players who completed the correction of biomechanical interventions and the neck rehabilitation programme are therefore suggested as normative values (Figure 7.23).

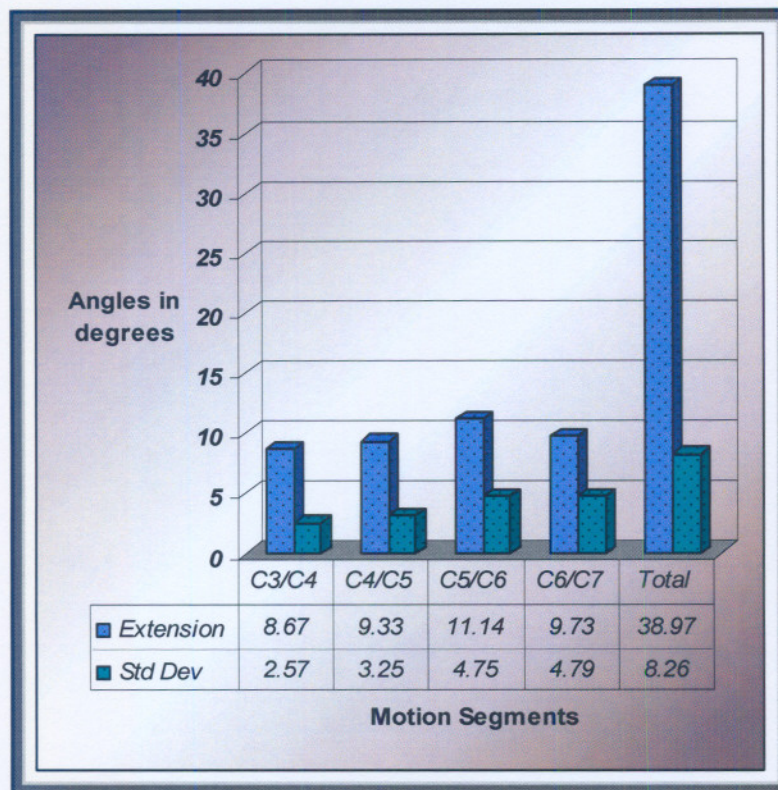


Figure 7.23: Normative extension angle measurements for cervical spine motion segments C3 to C7 as well as total extension.

The angles of rotation for the players who completed the neck rehabilitation programme will be given in the following section. Results will be given according to the various compliance groups.

7.6.2.3 Results for the Angles of Rotation following the Rehabilitation programme

The angles of rotation were calculated in the same way as for the x-ray measurement following the manual physiotherapy and therapeutic exercise programmes. The results of the various motion segments will be given in Tables 7.30 to 7.33, starting with the C6/C7 motion segment. The improvement in angles of rotation was moderately significant for all the compliance groups with effect sizes ranging from $d = 0.515$ for the group excluding compliance to $d = 0.689$ for the objective compliance group (Table 7.30).

Table 7.30: Results for the angles of rotation for the C6/C7 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	14.03	4.99	16.27	5.34	0.515
Objective compliance	13.97	4.84	16.76	5.52	0.689
Subjective compliance	14.07	5.45	16.42	5.74	0.535

The results for the angles of rotation for the C5/C6 motion segment show moderate statistical significant improvement for the group excluding compliance ($d = 0.493$) and the group with objective compliance ($d = 0.516$). The improvement for the group with subjective compliance was only of small significance ($d = 0.245$). These results are given in Table 7.31.

Table 7.31: Results for the angles of rotation for the C5/C6 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	14.78	5.17	18.28	5.45	0.493
Objective compliance	14.77	5.39	18.66	5.23	0.516
Subjective compliance	14.41	4.46	15.75	5.67	0.245

A decrease in the mean angles of rotation of moderate significance was seen for all the compliance groups for the C4/C5 motion segment (Table 7.32). These results demonstrate effect sizes ranging between $d = -0.626$ and -0.691 for the subjective compliance and for the group excluding compliance respectively.

Table 7.32: Results for the angles of rotation for the C4/C5 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	16.80	4.83	8.88	10.56	-0.691
Objective compliance	15.94	4.54	9.14	9.80	-0.630
Subjective compliance	16.85	5.43	9.84	10.16	-0.626

The same trend as for the C4/C5 motion segment was seen in the results of the C3/C4 motion segment with a decrease in mean angles of rotation (Table 7.33). A decrease in mean angles of rotation was seen with effect sizes ranging from $d = -0.362$ for the group with objective compliance to $d = -0.544$ for the group with subjective compliance.

Table 7.33: Results for the angles of rotation for the C3/C4 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	14.17	4.29	9.15	9.37	-0.458
Objective compliance	13.56	4.30	9.69	9.06	-0.362
Subjective compliance	14.98	4.48	9.00	8.30	-0.544

The increase in the angles of rotation for the C5/C6 and C6/C7 motion segments followed the trend seen in the results following the correction of cervical biomechanical dysfunction seen for Groups 1 and 2. The decrease in the angles of rotation as seen for the C3/C4 and C4/C5 motion segments is however not in keeping with the results seen for groups 1 and 2. The standard deviations for the mean angles of rotation for these motion segments are large, as can be seen in Table 7.32 and 7.33

indicating a very large variance in the results of the angles of rotation. The mean angles of rotation calculated from the third x-ray sets could however still be used as normative values for the schoolboy rugby players between the ages of 15 and 18 years (Figure 7.24).

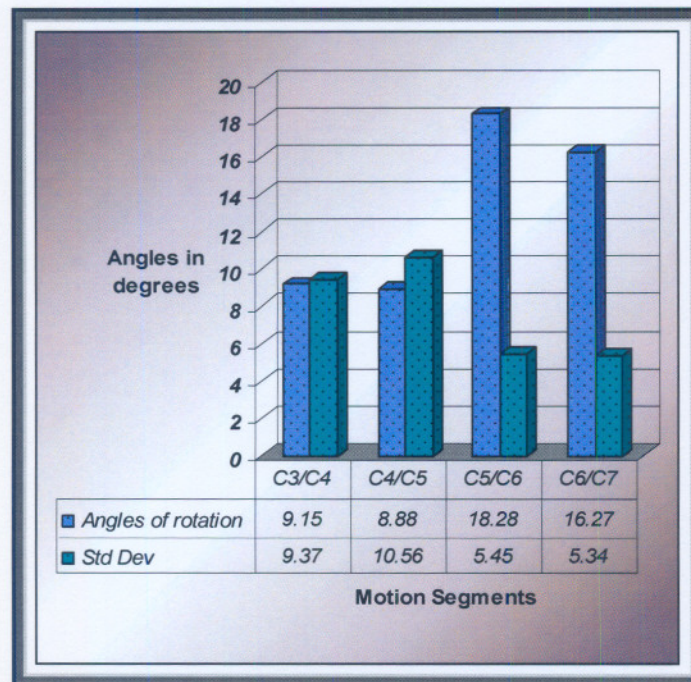


Figure 7.24: Normative angles of rotation measurements for cervical spine motion segments C3 to C7.

The following section will present the results for the translation measurements as measured for the third sets of x-rays following the neck rehabilitation programme.

7.6.2.4 Results for the Translation Measurements following the Neck Rehabilitation Programme

The results for the translation measurements of the various motion segments will be given in Tables 7.34 to Table 7.37, starting with the C6/C7 motion segment. A small statistical significant increase in translation was demonstrated for the mean translation considering the various compliance groups (Table 7.34). Effect sizes ranged between

$d = 0.3$ for the objective compliance group and $d = 0.44$ for the subjective compliance group.

Table 7.34: Mean translation measurement results for C6/C7 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	4.64	8.53	7.44	4.48	0.334
Objective compliance	4.98	8.77	7.45	6.69	0.300
Subjective compliance	4.57	9.60	8.27	9.60	0.440

The results for the C5/C6 motion segment illustrated a decrease in translation following the neck rehabilitation programme (Table 7.35). This decrease was of very small statistical significance for all the compliance groups; the group excluding compliance $d = -0.186$, the objective compliance group $d = -0.232$ and the subjective compliance group $d = -0.112$.

Table 7.35: Mean translation measurement results for C5/C6 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	11.48	8.01	10.09	5.84	-0.186
Objective compliance	12.36	8.46	10.51	6.18	-0.232
Subjective compliance	12.43	7.5	11.48	6.89	-0.112

A similar trend to the one found for the C5/C6 motion segment was seen in the results of the C4/C5 motion segments, with a decrease in translation following the neck rehabilitation programme (Table 7.36). Effect sizes were however of very small

significance with effect sizes ranging from $d = -0.098$ for the subjective compliance group to $d = -0.288$ for the group excluding compliance.

Table 7.36: Mean translation measurement results for C4/C5 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	12.26	5.84	10.81	3.50	-0.288
Objective compliance	12.69	6.12	11.40	6.34	-0.256
Subjective compliance	13.60	5.43	13.11	7.00	-0.098

The translation measurement for the C3/C4 motion segments also followed the trend as seen for the C4/C5 and C5/C6, with a decrease in translation measurements (Table 7.37). The decrease was of small significance for the objective and subjective compliance groups with $d = -.0455$ and $d = -0.428$ respectively. The decrease for the group excluding compliance was of very small significance ($d = -0.098$).

Table 7.37: Mean translation measurement results for C3/C4 motion segment before and after the neck rehabilitation programme.

Compliance	Mean 2nd X-ray	Std Dev	Mean 3rd X-ray	Std Dev	d-value
Excluding compliance	13.60	5.43	13.11	7.00	-0.098
Objective compliance	15.94	5.60	13.68	5.69	-0.455
Subjective compliance	16.12	4.67	14.50	5.47	-0.428

The results of these translation measurements demonstrated a decrease in translation for the C3/C4, C4/C5 and the C5/C6 motion segments and an increase for the C6/C7 motion segment. In the literature review the movement from extension to flexion of

the cervical spine are associated with a small degree of translation of the superior vertebra on the inferior vertebra and the literature stated that this translation should be evenly distributed throughout the cervical spine. The increase of the C6/C7 motion segment could therefore be interpreted as improving the even distribution of translation between the various motion segments measured for this clinical trial.

Since no normative values for translation between motion segments of the cervical spines for schoolboy rugby players could be found in the literature, the end results following the neck rehabilitation and correction of biomechanical dysfunction interventions could be used as normative values (Figure 7.25). The translation measurements for the various motion segments are similar, therefore the findings of the literature review is confirmed (Chapter 4:75).

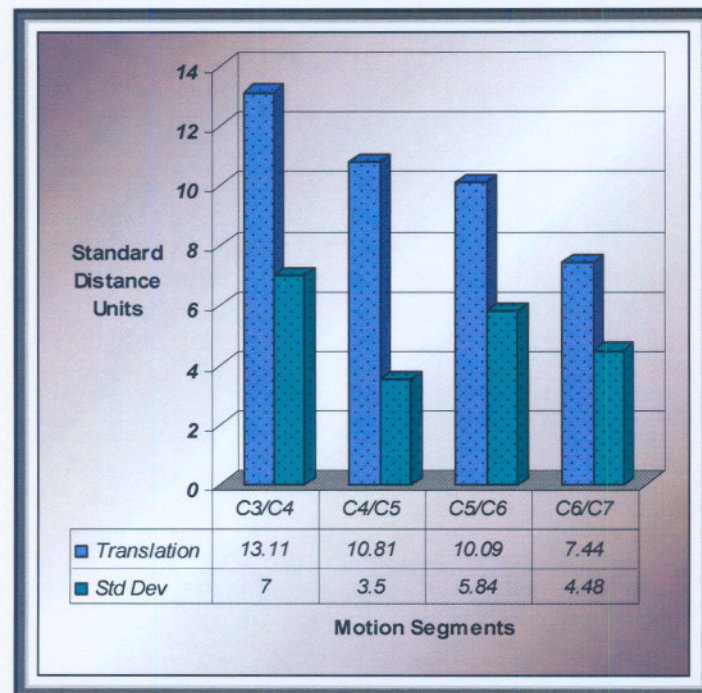


Figure 7.25: Normative translation measurements for cervical spine motion segments C3 to C7.

As stated before, no normative values for x-ray measurements of the motion segments of the cervical spine in schoolboy rugby players could be found in the literature reviewed. Therefore it is suggested that the x-ray measurements following the third

set of x-rays could be considered as a norm for this study population, namely schoolboy rugby players between 15 and 18 years of age. The mean values of all the x-ray measurements performed for motion segments from C3 to C7 following the neck rehabilitation programme are presented in figure 7.26. These results for each of the motion segments are within the normative ranges of motion as described by various authors (Magee, 1997:112, Bogduk & Mercer, 2000, Trew & Everett, 2001:218; Frobin *et al*, 2002) and therefore it could be assumed that the interventions studied did not result in hypermobile motion segments.

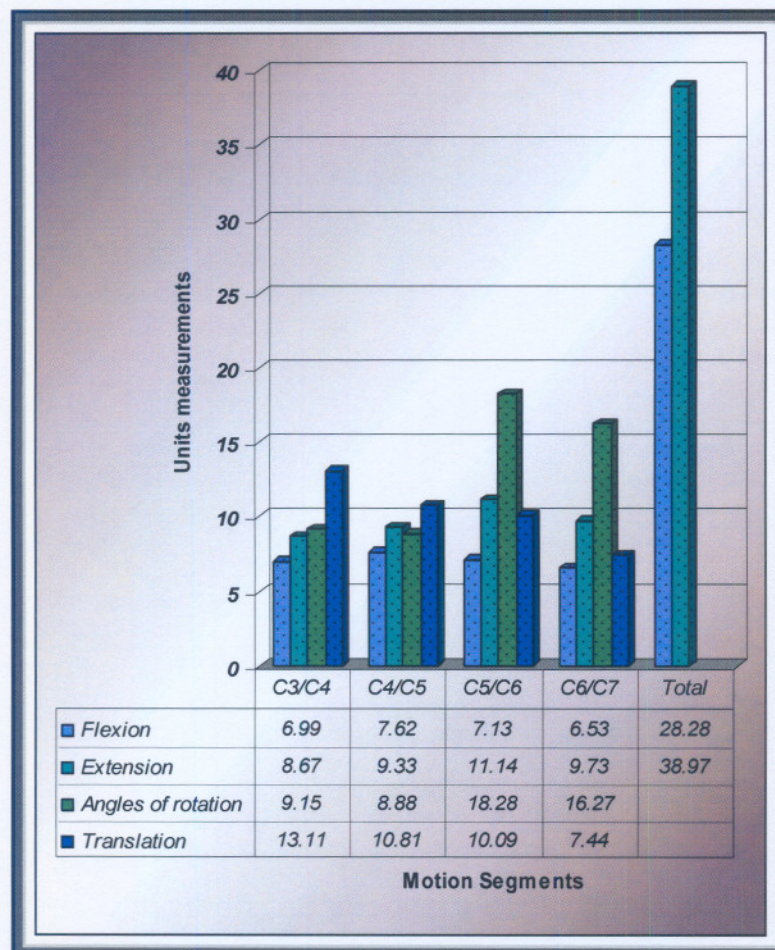


Figure 7.26: Normative values for all the x-ray measurements performed following the neck rehabilitation programme for cervical spine motion segments C3 to C7.

The possibility of a highly significant result following the neck rehabilitation programme was limited due to the fact the second x-ray measurements already showed a highly significant improvement for the group 1 subjects and a moderately significant improvement for group 2 players. Furthermore the group 3 players did not present with biomechanical dysfunction initially.

It could therefore be concluded that these results provide evidence that the neck rehabilitation programme not only maintained the improvement in cervical spine biomechanical function achieved by the manual physiotherapy technique and the therapeutic exercise programme, but further improved the biomechanical function of the cervical spines the players. The following section will theorise on possible explanations on why the rehabilitation programme improved the biomechanical dysfunction.

7.6.2.5 Explanation for the Improvement in Biomechanical Function following the Rehabilitation Programme.

For the same reason that the rehabilitation programme indicated an improvement in the cervical circumference of the players who did not comply fully with the rehabilitation programme, the biomechanical dysfunction could also be explained. The emphasis placed on all the components of a therapeutic exercise programme (Chapter 4:86), including motor control and motor learning of normal movement patterns, dynamic stability and establishing feedforward mechanisms could explain the improvement.

According to Bulter and Moseley (2003:22-23) the sensory homunculus need to review sensory input of movement continuously to maintain representation of the area in the primary sensory area. In the case of a limb amputation the sensory representative area of the homunculus in the cortex decreases in size after approximately three days. The representative area in the motor homunculus also decreases because the muscles represented in this area are not being used. Research by Holm et al (2002) studying the sensorimotor control of the spine found that spinal structures including the intervertebral disc, facet joint capsule and ligaments abundant

in afferent structures. Electrical stimulation of these afferents in the lumbar spine seemed to elicit reflex contraction of the multifidus and longissimus muscles. Mechanical stimulation of these structures excites the muscles. Therefore normal movement and a bombardment of afferent sensory input to the sensory homunculus provided by the rehabilitation programme could be sufficient to improve and refresh the cervical spine representation of the sensory homunculus.

It has also been suggested that, in order to simplify the sensory input from the peripheral nervous system, the CNS uses the position of the trunk as a reference for the position of the more distal segments in the limbs (Hodges, 2004). For the schoolboy rugby player this means that he should stabilise his neck and head when performing skills which require coordination of the upper limb.

Each of these components of neuromuscular control described before (Chapter 4:106) has been implicated in association with neuromusculoskeletal pain and therapeutic exercise interventions have been developed to address these deficits. This study address all these components in the rehabilitation programme for the schoolboy rugby players not to treat pain as the result of neuromusculoskeletal dysfunction, but in an attempt to improve these components with the aim being the prevention of pain and disability later in life.

Therefore this constant refreshment provided by the developed rehabilitation programme could provide the answer for the improved dynamic biomechanical function of the motion segments of the cervical spine.

7.6.3 Role of the Educator in the Neck Rehabilitation Programme

The educator in this case could be any designated skilled person appointed by the school to implement this neck rehabilitation programme for the schoolboy rugby players. One of the biggest problems incurred by the researcher during the study was the compliance of the subjects with the rehabilitation programme. It could be part of the seemingly demotivated culture experienced by adolescents now. Ninety-five

percent of the players who completed the initial questionnaire stated that they believed that a strong neck could reduce their chances of sustaining a neck injury. Not even this knowledge could motivate the players to comply with the rehabilitation programme.

Generally with the high level of competition experienced in school rugby, the team players will follow the training programme performed at training with enthusiasm, but home exercises are not done, with only 4.3 % of players who completed the initial questionnaire prior to the start of the interventions, performing any neck exercises at home. The importance of the rehabilitation programme was discussed with the coaches and players prior to the start of this investigation and they were all in agreement with performing the rehabilitation programme during training. This proved not to be the case. Players gave feedback that before important matches training was spent on strategic planning and tactics with the rehabilitation programme not being performed.

The majority (92.4 %) of the players who completed the initial questionnaire stated that their coach was the person who taught them the neck exercises they performed, but 67 % of these players felt that their coach did not have sufficient knowledge about neck exercises. Therefore the challenge for the educators and coaches as well as the healthcare professional involved with the schoolboy rugby player will be to become knowledgeable as far as neck rehabilitation is concerned. These role players will also have to motivate the players to perform their neck rehabilitation by possibly including the neck rehabilitation programme in training and performing the programme diligently. Therefore a recommendation of the study will be to spend more time teaching the exercises to the trainers so that they become familiar with the exercises and implement them for their teams.

This neck rehabilitation programme not only proved to be effective in strengthening the neck muscles of all the players who completed the programme, but the results of the x-ray measurements before and after the rehabilitation programme also showed an improvement in biomechanical function of the cervical spine.

The following section will provide and discuss the results of all the factors that could predispose a player to biomechanical dysfunction of the cervical spine.

7.7 Factors which could Predispose a Schoolboy Rugby Player to Cervical Spine Biomechanical Dysfunction

According to the literature the following factors could predispose an individual to the development of biomechanical dysfunction (Chapter 4:82). It was therefore decided to statistically analyse these factors for possible relevance in affecting biomechanical function of the cervical spines in all the subjects participating in this clinical trial. The following section will provide and discuss the results of these factors as having a possible influence of the biomechanical dysfunction found in the schoolboy rugby players. The possible influence of these factors on the outcome of this study will subsequently be argued for each factor.

7.7.1 Results for Posture possibly Influencing Biomechanical Function

To investigate a possible correlation between posture and biomechanical dysfunction the mean flexion angle was compared with each of the posture variants used in the study. The Eta squared analysis was used to determine a possible correlation between each cervical spine motion segment and the various posture types (Chapter 6:176) for all the subjects participating in this clinical trial. The results for each of the four groups are given separately. The mean flexion angles measured for the first set of x-rays were correlated with the various posture types, since restriction of the flexion movement was the biomechanical dysfunction mostly found in the schoolboy rugby players (Chapter 6:170). The results of this comparison is given in Figure 7.27. Only the motion segments that showed correlation are illustrated, the motion segments that did not show any correlation are omitted. Eta squared values were interpreted as 0.01

as a small significant effect, 0.06 as a moderate significant effect and 0.14 as being of high statistical significance.

For Group 1 only the C6/C7 motion segment showed any correlation with an Eta squared value of 0.116, which is of high statistical significance. The results for Group 2 indicated a highly statistically significant correlation between posture and the mean flexion angle for the C4/C5 motion segment with an Eta squared value of 0.169. For the C5/C6 and C6/C7 motion segments the correlation was very small with Eta squared values of 0.072 and 0.044 respectively. The results for the players of Group 3 were highly significant for the C3/C4, C4/C5 and C5/C6 motion segments with Eta squared values of 0.137, 0.162 and 0.306 respectively. For the control group (Group 4) the C4/C5 and C6/C7 motion segments showed very weak correlation with Eta squared values of 0.033 and 0.086 respectively.

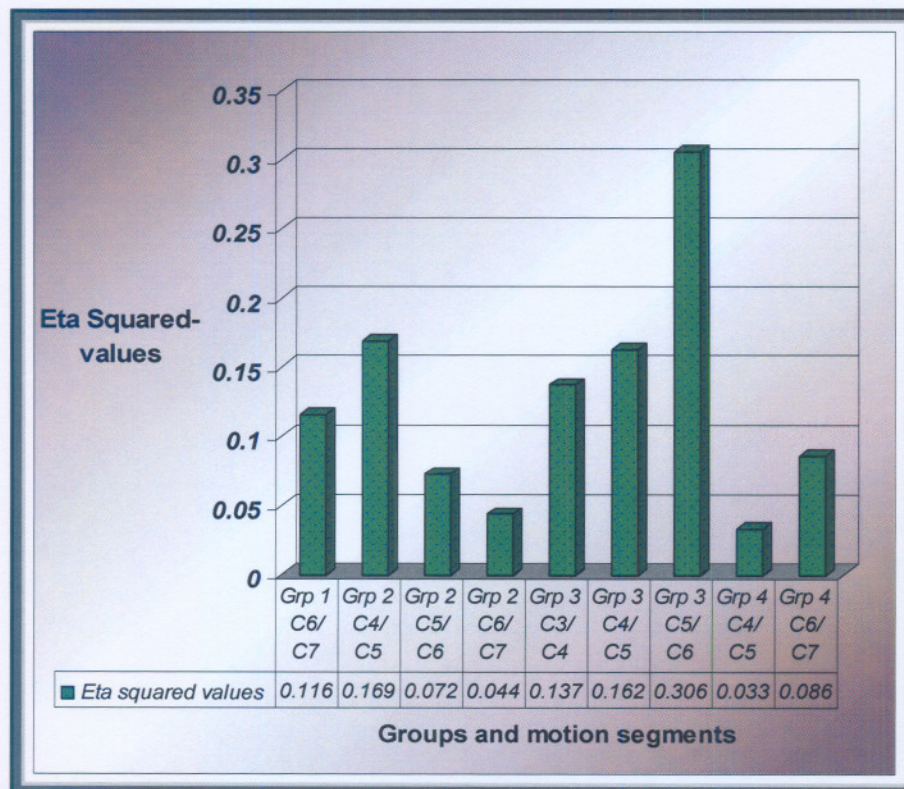


Figure 7.27: Eta squared values illustrating the correlation between posture and biomechanical dysfunction for the various Groups.

The results above show an inverted result. Group 3 consist of players without biomechanical dysfunction and the largest statistical significance was found between posture and dysfunction for this group. For Group 1 the significance were strong for only one motion segment and for Group 2, the other group with biomechanical dysfunction, the correlation was weak for only two motion segments. It could be theorised that the correlation could not be proven, since the biomechanical dysfunction found involves extension of the lower cervical spine and not flexion, as suggested by a forward neck posture, the posture type most common in the schoolboy rugby players. Therefore it could be concluded that for this particular study population biomechanical dysfunction of the cervical spine does not correlate well with poor posture and therefore the poor posture found in some of these players could not have influenced the results of the study.

The following tables (Tables 7.38 to 7.46) present the results of the posture variations with their corresponding mean flexion angles as well as standard deviations. Only the motion segments where a correlation was found will be illustrated.

Table 7.38: Mean flexion angles for the various posture types for Group 1, C6/C7 motion segment.

Posture	n	Flexion angle	Std Dev
Neutral spine	9	2.23	2.71
Kyphosis - Lordosis	3	4.17	3.08
Flat back	1	1.20	
Sway back with forward head posture	3	-0.47	3.29
Forward neck posture	8	2.64	4.55
Scoliosis	1	-7.10	

Table 7.39: Mean flexion angles for the various posture types for Group 2, C4/C5 motion segment.

Posture	n	Flexion angle	Std Dev
Neutral spine	13	-7.90	3.49
Kyphosis - Lordosis	1	4.80	
Flat back posture	1	-7.90	
Sway back posture	2	-5.50	1.76
Sway back with forward head posture	2	-2.20	5.09
Forward neck posture	6	-4.68	5.88

Table 7.40: Mean flexion angles for the various posture types for Group 2, C5/C6 motion segment.

Posture	n	Flexion angle	Std Dev
Neutral spine	13	-4.36	4.73
Kyphosis - Lordosis	1	-1.40	
Flat back posture	1	-14.70	
Sway back posture	2	-3.75	1.77
Sway back with forward head posture	2	-5.85	3.04
Forward neck posture	6	-1.28	5.39

Table 7.41: Mean flexion angles for the various posture types for Group 2, C6/C7 motion segment.

Posture	n	Flexion angle	Std Dev
Neutral spine	13	-1.72	4.13
Kyphosis - Lordosis	1	-7.20	
Flat back posture	1	-8.90	
Sway back posture	2	-1.05	2.90
Sway back with forward head posture	2	2.35	7.71
Forward neck posture	6	0.42	4.77

Table 7.42: Mean flexion angles for the various posture types for Group 3, C3/C4 motion segment.

Posture	n	Flexion angle	Std Dev
Neutral spine	8	-6.79	2.08
Kyphosis - Lordosis	1	-1.70	
Kyphosis - Lordosis and forward head posture	1	-13.20	
Flat back posture	1	-2.60	
Sway back with forward head posture	2	-7.15	0.35
Forward neck posture	11	-5.57	3.40
Scoliosis with forward head posture	1	-6.00	

Table 7.43: Mean flexion angles for the various posture types for Group 3, C4/C5 motion segment.

Posture	n	Flexion angle	Std Dev
Neutral spine	8	-7.55	3.36
Kyphosis - Lordosis	1	0.70	
Kyphosis - Lordosis and forward head posture	1	-8.80	
Flat back posture	1	-12.60	
Sway back with forward head posture	2	-10.00	2.69
Forward neck posture	11	-6.21	3.21
Scoliosis with forward head posture	1	-4.30	

Table 7.44: Mean flexion angles for the various posture types for Group 3, C5/C6 motion segment.

Posture	n	Flexion angle	Std Dev
Neutral spine	8	-6.66	3.27
Kyphosis - Lordosis	1	0.70	
Kyphosis - Lordosis and forward head posture	1	-5.40	
Flat back posture	1	-9.90	
Sway back with forward head posture	2	-5.47	4.17
Forward neck posture	11	-5.47	4.17
Scoliosis with forward head posture	1	7.70	

Table 7.45: Mean flexion angles for the various posture types for Group 4, C4/C5 motion segment.

Posture	n	Flexion angle	Std Dev
Neutral spine	10	-8.11	3.48
Sway back posture	1	-0.80	
Sway back with forward head posture	2	-10.40	6.36
Forward neck posture	10	-5.67	5.38

Table 7.46: Mean flexion angles for the various posture types for Group 4, C6/C7 motion segment.

Posture	n	Flexion angle	Std Dev
Neutral spine	10	-2.18	3.10
Sway back posture	1	7.20	
Sway back with forward head posture	2	1.50	8.91
Forward neck posture	10	-3.53	5.50

The neutral spine position of the cervical spine as maintained with proper posture is the best for spinal support of weight and the muscles can generate the most force with the greatest efficiency while working in that position or from that position. The importance of body segment position is especially illustrated in the head, where changes in its anterior-posterior position greatly affect how much work is necessary to support it (Magee, 1997:697).

The head-neck support system could be linked to a 4 kg ball on a flexible shaft, stabilised by guy wires. The least stress on the spine would occur when the head is centred over the spinal column with the force being transmitted through the posterior third of the vertebral column (Rocabado, 1999). Each centimetre that the head moves forward requires increased exertion by the muscles to support the head, which means

that there is less muscle strength available to support outside loads. This is especially relevant to the front row schoolboy rugby player whom cannot afford any factor reducing the effort of the neck musculature.

Forward head posture involves flexion of the lower cervical spine with extension of the upper cervical spine. This pattern is the reverse of what could be expected in the schoolboy rugby players, since their lower cervical spines are held in extension. In the general population the incidence of forward head posture is very high (Magee, 1997:701). Posture could therefore be one of the factors which could contribute to the biomechanical dysfunction found in the cervical spines of schoolboy rugby players.

For optimal posture however normal biomechanics is a prerequisite. In the event of biomechanics dysfunction the weight bearing line does not pass through the posterior third of the cervical spinal column and therefore the subject would not be able to maintain optimal posture. Optimal posture also requires correct muscle flexibility and strength balances and if this is the case proper posture can be maintained without conscious effort at all times. Therefore the elements for optimal posture are correct biomechanical function, normal muscle flexibility and normal strength and balances of the neck musculature. It is therefore needless to teach correct posture to a schoolboy rugby player if he has biomechanical dysfunction, muscle shortening and weakness.

Since forward head posture and khyphosis worsens with age, it is of utmost importance that poor posture is corrected at an early age (Jordaan, 2004). Maintaining proper posture, flexibility and range of motion may help minimise age-related decline in physical performance. The rugby coach or healthcare professional involved in the training of the schoolboy rugby player is therefore in the perfect position to be instrumental in the possible reduction of bad posture.

7.7.2 Age and Anthropometric Measurements results

The various groups compared well to one another at the start of the clinical trial as far as the anthropometric measurement were concerned as can be seen in the following

table (Table 7.47). At the start of the investigation the following measurements were considered: age, years participation in rugby, initial body mass and initial cervical circumference.

Table 7.47: Mean anthropometric measurements for the various groups.

Group	Age	Years Participation in rugby	Initial Body Mass	Initial Cervical Circumference
Group 1	16.44	10.00	78.70	38.43
Group 2	16.60	9.68	82.24	39.70
Group 3	16.36	10.00	75.27	38.24
Group 4	16.43	9.26	70.01	37.74

7.7.3 Upper cervical spine Ligament stability results

Instability of the upper cervical spine could influence the biomechanics of the rest of the cervical spine (Bogduk & Mercer, 2000). No instability of any of the ligaments of the upper cervical spine was found in any of the players in any of the groups, therefore this could not have been a factor influencing the biomechanics of the cervical spine for the present study.

7.7.4 Results of the Neurodynamic testing

The purpose of neurodynamic testing is to determine whether there is any restriction in the movement of the neural structures of the upper limb. If any of the exiting nerve roots of the brachial plexus from the lower cervical spine are entrapped, a restriction of the movement pattern performed during this neurodynamic test will be perceived. Such an entrapment could influence the normal biomechanics of the cervical spine. However, no restriction of the neurodynamic test was found in any of the players to suggest any impingement or irritability of the neural structures of the neck and upper limb, therefore neurodynamic structures could have had no influence on the biomechanics of the cervical spine for this clinical trial.

7.7.5 Results for Playing Position

To investigate whether there was any correlation between playing position and biomechanical dysfunction of the cervical spine the total flexion and extension measurement for all the forward players were compared with the same measurements for the back players. These results are illustrated in Figure 7.28. There were very small differences in the total flexion and extension angles between the forwards and the backs. The backs had a slightly smaller total flexion angle than the forwards, meaning that they had slightly more of a biomechanical dysfunction than the forward players. The forwards and backs were well matched in terms of numbers and mean age.

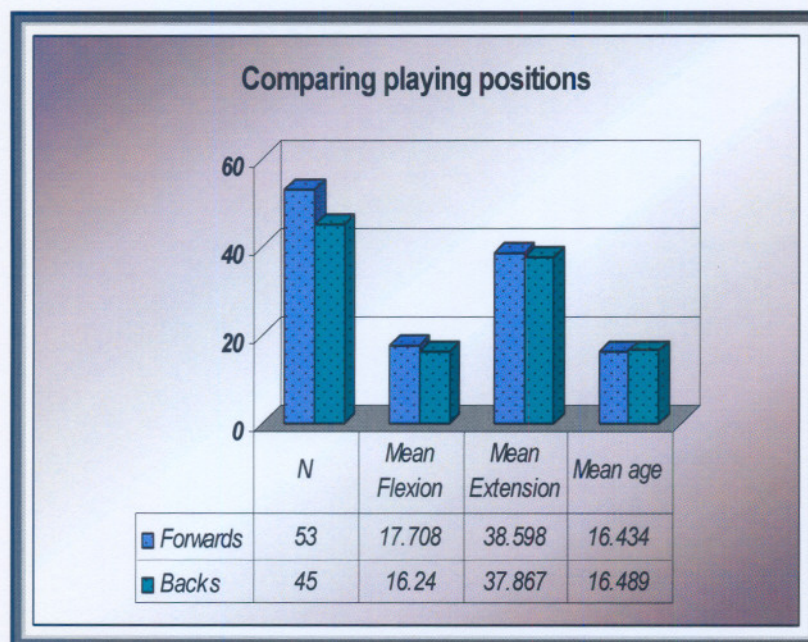


Figure 7.28: Comparison between forwards and backs.

From the literature it was expected that the forward players should be more predisposed to biomechanical dysfunction of their cervical spines, due to the loads being placed on the necks of these players during the scrum, then the back players. The majority of players (92%) who completed the initial questionnaire also stated that forwards were at greater risk of injuring their necks than the backs.

The results of this study could not confirm this. It was found that the backs had slightly less flexion movement than the forward, indicating more of a biomechanical dysfunction. This finding could be explained by the following. The risk to the schoolboy rugby player to develop biomechanical dysfunction could be equally high during the tackling and mauling phases of play, where the backs are also involved frequently, as during scrumming. During a tackle the C5/C6 motion segment often is the point of contact (Chapter 5:149). According to O'Brien (1996) the mechanism of injury to the front row players during scrumming is the direct contact on the C6-T2 spinous processes. This could be why the incidence of biomechanical dysfunction found in the schoolboy rugby players was mostly the lower cervical spines.

The following section will argue the possible prevention of cervical spinal cord injuries following the results of this clinical trial. It was not within the scope of the study to prove a reduction in spinal cord injuries following the implementation of this programme, but the theory on how these results could possible reduce the number of spinal cord injuries if the therapeutic exercise programme for the correction of biomechanical dysfunction as well as the neck rehabilitation programme could be implemented for all schoolboy rugby players.

7.8 Prevention of Cervical Spinal Cord Injuries

The cervical spine biomechanical dysfunction mostly found in these schoolboy rugby players was a flexion restriction of the motion segment of the lower cervical spine (chapter 6:169). These lower cervical spinal motion segments are often held in the extension and subsequently do not follow the normal pattern of movement in flexion. Hypothetically this would imply that in the example of the front row player, where the scrum collapses and the player's neck is forced into more flexion, the motion segments of the lower cervical spine is unable to move optimally. This reduced range of motion could strain the posterior structures to the point of failure, causing dislocation of the facet joints.

According to the literature reviewed the cervical spine level which most often dislocates causing spinal cord damage is the C5/C6 motion segment of the cervical spine. The results of this study found they highest incidence of biomechanical dysfunction at the C5/C6 motion segment and this was also the level which showed the best improvement. It could be theorised that the correction of biomechanical dysfunction and the rehabilitation of the neck muscles may reduce the risk of spinal cord injury in the schoolboy rugby player.

Additional mechanisms of injury for cervical spine dislocation are flexion combined with rotation as well as straightening of the cervical spine, creating a column and obliterating the cervical lordosis. The restricted movement pattern most commonly found in this study by means of the physiotherapy evaluation technique is rotation of the cervical spine with lateral flexion to the opposite side. During a tackle performed by a player the neck is flexed and tucked behind the opponent's shoulder. The point of contact for the player performing the tackle is the C5/C6 area on the side of the tackling player's neck. After contact is made on the opponent, the neck of the tackling player could be forced into lateral flexion to the opposite side. This is the movement pattern found to be restricted in the schoolboy rugby players evaluated during this study. In addition to this the player could also receive an axial load on the top of his head. This scenario is often seen in a rugby match or rugby training session with maximum risk of dislocation of the facet joints of the cervical spine. Correction of the dysfunction and correction of the restricted movement pattern could therefore reduce the risk of injury dramatically.

As stated earlier Noakes et al (1999) proposed an intrinsic risk factor which could predispose the rugby player to cervical spinal cord injury. With reference to the discussion above the researcher proposes that the intrinsic risk factor in the schoolboy rugby player may be the biomechanical dysfunction found by the present study. This programme has been evaluated as being safe in the absence of biomechanical dysfunction and should be implemented, for all schoolboy rugby players which could show a reduction in cervical spinal cord injury. It is suggested by this researcher that a long term follow-up study need to be considered to scientifically and clinically validate this belief.

The present Chief Executive Officer of the Sports Science Institute at the University of Cape Town, the former Springbok captain Morne du Plessis, stated that there will always be the odd freak accident with a game like rugby, but if players are properly prepared and if rugby is organised with good coaching and refereeing we can eliminate a large number of injuries. It is self evident that one must focus on the preventative rather than the curative. If only one fractured neck a year can be avoided it is a job well done according to. Lynn Allan, manager of the Chris Burger / Petro Jackson Players' Fund. She also said that their research showed that the rural areas are a major source of concern. Due to lack of sufficient funding their medical equipment usually only consists of a bag of ice and an old door as a spine board. The positive results of the rehabilitation programme of this study could be implemented in these areas through training for the coaches and this could aid in the prevention of injuries, rather than having to treat players following an injury. The Player's Fund is asked to assist financially with approximately 10 new cases every year (Scher, 2004).

It is strongly recommended by the researcher that the therapeutic exercise programme for the correction of biomechanical dysfunction as well as the rehabilitation programme be implemented as part of the training programme for all schoolboy rugby players in South Africa. The programme is cost effective and safe and with training workshops the coaches of rugby teams in the rural areas could be taught how to implement the programme.

The following section will reflect on how the therapeutic exercise programme for the correction of biomechanical dysfunction as well as the neck rehabilitation programme could possibly contribute to the prevention of early degeneration found in the cervical spines of rugby players.

7.9 Prevention of Early Cervical Spine Degeneration

Dysfunction of the cervical spine can lead to degeneration resulting in pain and disability. Causality of lower back pain is thought to arise from damage to the intervertebral disc or the facet joints, either directly through trauma injuries or disc prolapse, or indirectly through the degenerative process that transmit unfavourable

loading patterns to other spinal structures for example joints, ligaments, tendons and supporting musculature. These mechanisms behind spinal disorders can either act as single variables or in combination (Holm *et al*, 2002).

The theory behind the aetiology of early degeneration of the cervical spine, such as found by Scher (1991) in the cervical spines of rugby players strongly indicates that the prevention of this degenerative process could be achieved by the various interventions investigated in this study.

As stated earlier, joints should be in a physiological state of rest or neutrality, with the least amount of intra-joint pressure, least amount of connective tissue tension and the least amount of electromyographic (EMG) muscle activity. For the cervical spine this would mean a lordotic curve with the weight bearing line passing through the posterior third of the vertebral bodies. Theoretically this neutral position would suggest the minimum wear and tear that will be placed on the various motion segments of the cervical spine. This neutral spine position is graphically illustrated in Figure 7.29.

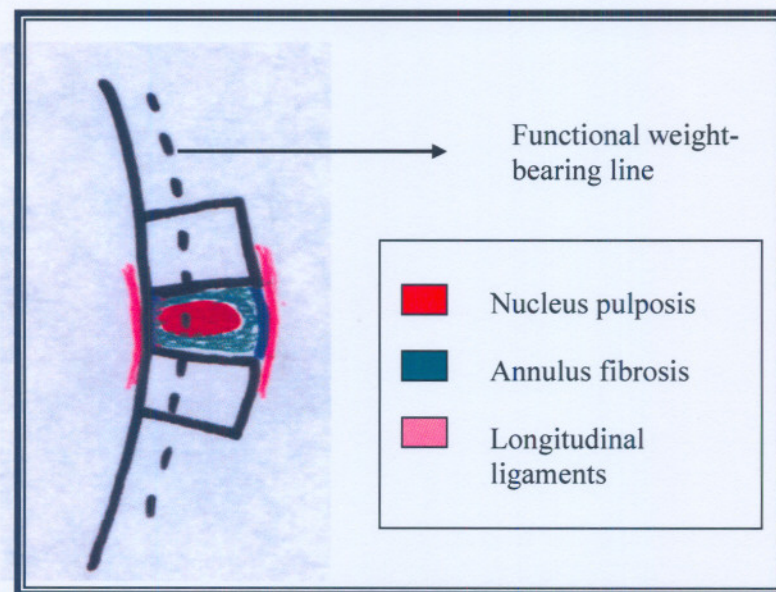


Figure 7.29: A schematic illustration of the normal biomechanics of the cervical spine with the functional force being transmitted through the posterior third of the vertebral body.

When motion segments are held in a state of immobilisation, which means that the motion segment is unable to move normally in the three planes of space resulting in a positional fault, or dysfunction, occurring. This places additional strain on the motion segments with an increased amount of wear and tear, resulting in possible degenerative changes. The positional fault which was most commonly found in the sample of schoolboy rugby players studied was the motion segments of the lower cervical spine held in extension.

Global range of motion of the cervical spine could compensate for this decrease in flexion motion with slipping (translation) of the vertebra above. As stated earlier Kaigle et al (1997) have shown that in the lumbar spine this kind of hypermobility does not seem to occur, but that the motion pattern is greatly altered. Their results were confirmed in this study. A compensatory increased amount of flexion was found for the motion segment proximal to the motion segment held in extension. An example of the flexion x-ray with marked measurements for one of the players of Group 1, prior to the start of the manual physiotherapy treatment is given in Figure 7.30. Note that the C5/C6 motion segment is positioned in 10.5° of extension, while the C4/C5 motion segment is positioned in 3.6° of flexion and the C3/C4 motion segment is positioned in 3.1° of extension.



Figure 7.30: Flexion x-ray measurement for the motion segments of one of the players from Group 1, prior to the manual physiotherapy treatment.

The increased amount angle of flexion in the motion segment adjacent to the segment held in extension possibly exerts large amounts of strain on the posterior fibres of the annulus fibrosus and this could theoretically result on fissuring of the annulus. With flexion the posterior wall of the capsule of the disc is opened and this may cause the outer rings of the annulus fibrosis of the disc to be torn (Dai *et al*, 1992). This is graphically illustrated in Figure 7.31.

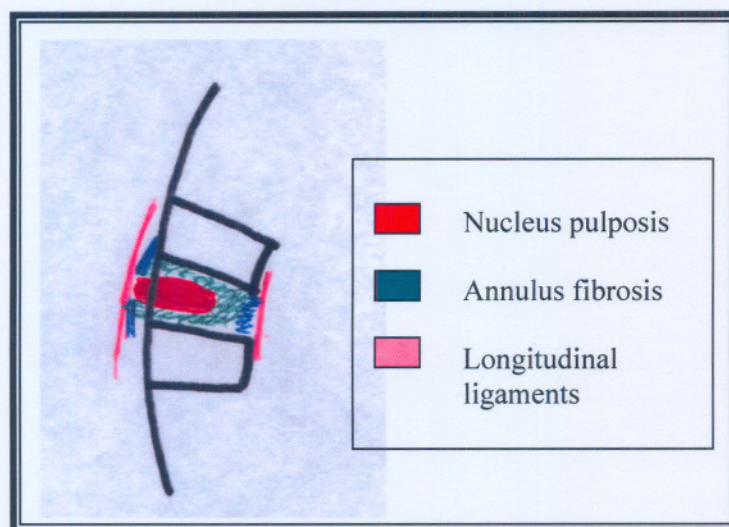


Figure 7.31: A schematic illustration of the effect that excessive flexion could have on the posterior fibres of the annulus fibrosus of the intervertebral disc.

A study by Thompson et al (2004) investigated the mechanical effect of intervertebral disc lesions. They performed an in vitro dynamical mechanical testing of sheep discs comparing its mechanical behaviour before and after creating discs lesions. They concluded that rim lesions reduced the disc's ability to resist motion and that radial tears change the hysteresis of response, indicating an altered stress distribution within the disc. The importance of this notion for the schoolboy rugby player is that should a radial tear occur, it will have a negative impact on the ability of the cervical spine to resist motion in high risk situations. This will predispose the player to severe injury. This could become a vicious cycle that could result in early degenerative changes of the cervical spine. The results of the various interventions clearly indicated that the flexion angles of the motion segments during flexion were normalised. The results of the same player demonstrated earlier in Figure 7.30 (Chapter 7:283) will be discussed to demonstrate this normalisation. The improvements in the flexion angles of the motion segments following the manual physiotherapy treatment is illustrated in Figure 7.32. Note that all the motion segment are now positioned in flexion during flexion movement of the cervical spine.

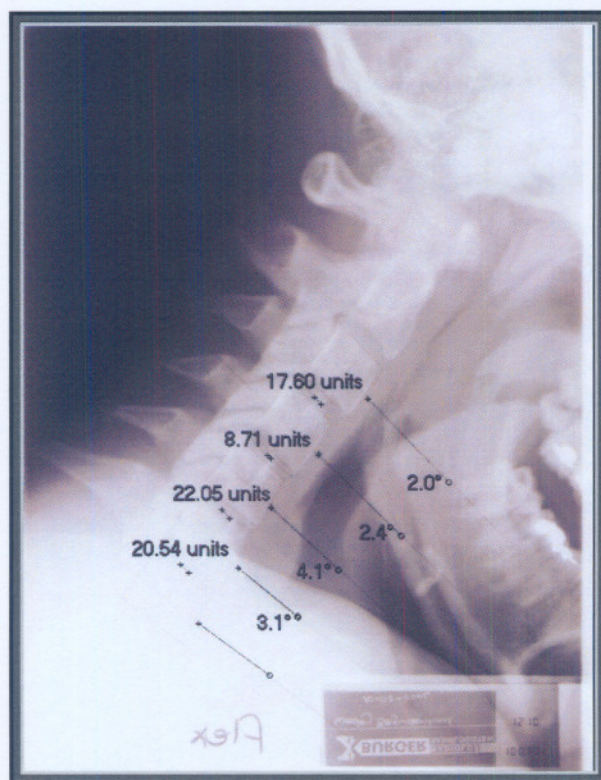


Figure 7.32: Flexion x-ray measurement for the motion segments of one of the players from Group 1, after the manual physiotherapy treatment.

A further improvement in the flexion angles of the motion segments are seen in the final flexion x-ray, following the neck rehabilitation programme (Figure 7.33). The improvement from the first x-ray (Figure 7.30) therefore clearly illustrates a restoration of cervical biomechanical function of this particular schoolboy rugby player.

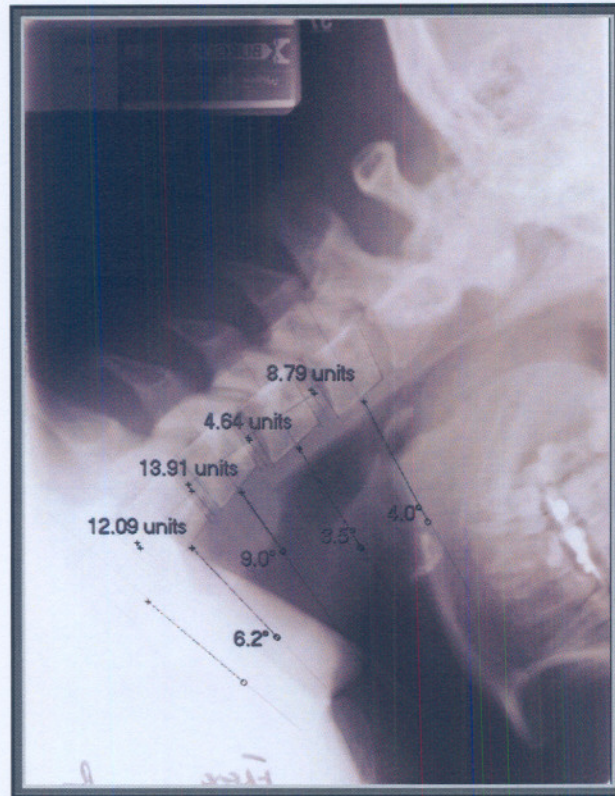


Figure 7.33: Flexion x-ray measurement for the motion segments of one of the players from Group 1, following the neck rehabilitation programme.

Dysfunction of a motion segment could also impact on all the soft tissue structures surrounding the motion segment. Once a particular joint becomes hypomobile and loses its normal arthrokinetics the muscles around that joint attempt to minimise the strain on the affected joint and subsequently some of the muscles become shortened and hypertonic. This in turn affects both the synergistic and the antagonistic muscles resulting in a complex neuromusculoskeletal dysfunction (Prentice, 2004:132). In the case of the schoolboy rugby players the identified hypomobile motion segments could therefore result in neuromusculoskeletal dysfunction if left uncorrected. Uhlig et al (1995) and Falla et al (2004) suggested that fibre transformation takes place in response to a large number of specific and non-specific stimuli for example physical training, immobilisation and pain. These changes were found to be independent of the type of pathology; thus there is no difference in the muscle fibre transformation that occurs following rheumatoid arthritis and the dysfunction found in the schoolboy

rugby players. It could therefore be inferred that such fibre transformation could occur in the schoolboy rugby player, where one or more of the motion segments of the cervical spine are held in a state of immobilisation due to biomechanical dysfunction. This transformation was found to be of limited duration and terminated after approximately two to three years despite the persistence of symptoms.

Altered motion caused by biomechanical dysfunction could result in changes in length and loading of the muscles and ligaments and this may result in altered firing patterns and changes in the coordination pattern of the muscles. The consequence of this to the schoolboy rugby player could be devastating if the motion segments do not respond optimally during a high risk situation such as a tackle. Mechanical deformation of the motion segment could also result in reflex muscle spasm of the muscles surrounding the motion segment and therefore affect the function of the muscles and reduce their efficacy in the stabilisation of the segment. As stated earlier the facet joints have a regulatory function in controlling the intricate neuromuscular balance in the motion segment. If the facet joints do not move through full range of motion, as found in the schoolboy rugby players, the ability of the facet joints to regulate and control neuromuscular balance could be impaired (Kaigle *et al*, 1997).

It is well known that pathology does not have as a direct consequence pain. Many people with severe degenerative changes in their cervical spines suffer no pain. Social circumstance, emotional wellbeing and belief systems would contribute to the experience of pain. Many of the structures that could be injured in the cervical spines of the schoolboy rugby players could become symptomatic. For the current study neck pain was taken as an exclusion criterion. All the severe dysfunction found in the schoolboy rugby players were therefore not an indication for pain. As suggested the strain on the posterior annulus fibrosis could be huge with tearing of some of the fibres. A study performed by Holm *et al* (2002) on pigs found that stimulation of the disc annulus fibrosis induced responses in the multifidus muscle on multiple levels and on the contralateral side.

The intervertebral disc itself may be a source of pain that originates from mechanical or chemical disturbances, since the outer third of the annulus fibrosis is innervated (White & Panjabi, 1990:390-391). Most of the nerve endings are concentrated in the

lateral region of the disc, with a smaller number in the posterior region and the least in the anterior region (Brinckmann, 1986).

As stated earlier the disc and the zygapophyseal joints are responsible for the mechanical guidance of the motion segment (Chapter 4:72). The facet joints are typical synovial joints and as such are richly innervated by sensory afferents. The muscles around the motion segments not only act as moment-producers, but also generate compressive and shear forces. Therefore the function of the muscles is to stabilise and mobilise the motion segments and also to provide proprioceptive input to higher centres. This is not only important for the feedback and feedforward mechanisms in the motor system, but also refreshes the sensory and motor homonculusses in the cerebral cortex. A study performed by Holm et al (2002) on pigs also found that stimulation of the facet joint capsule induced reaction predominantly on the same side and at the segmental level of the stimulation.

Articular cartilage plays a vital role in the function of the musculoskeletal system by allowing almost frictionless motion to occur between the articular surfaces of synovial joints. Articular cartilage also distributes loads of articulation over a larger contact area, thereby minimising the contact stresses and helps to dissipate the energy associated with the load (Cohen *et al*, 1998). These properties of articular cartilage allow the cartilage to remain healthy and fully functional throughout life, despite the slow turnover rate of its collagen matrix. Repetitive activities over a long period of time, such as load during participation in rugby, have been associated with degeneration, leading to osteoarthritic changes in the joint. Cohen et al (1998) concluded that regular lifelong exercise does not necessarily predispose a joint to osteoarthritis. Exercise in the setting of an abnormal joint, however, may predispose the joint to arthritic changes.

7.9.1 The Biomechanical Consequence of Degeneration.

The process of degeneration makes the disc less viscoelastic (White & Panjabi, 1991:9). In the case of disc degeneration the disc bulges more than twice the amount of a normal disc therefore a player with early degeneration is more prone to disc bulge

with consequent nerve root irritation than a person their age without disc degeneration (White & Panjabi, 1991:7). The shock-absorbing properties of the anterior and posterior longitudinal ligament decreases with age (White & Panjabi, 1991:250), therefore the player could be predisposed to greater trauma in the event of a cervical spine injury such as from a motor vehicle accident.

If the articular cartilage of the facet joint of the cervical spine is injured while playing rugby, the injured articular cartilage is unable to repair itself due to the lack of blood supply to the cartilage. This could be a contributing factor in the degenerative process of synovial joints (Whiting & Zernicke, 1998:126). Yang and King (1984) found that the load can increase by up to 47 % in the arthritic facet joint. For the rugby player this could have serious implication as predisposition for the development of pain and disability later in life. Silver (2002) concludes that rugby causes degenerative disease of the spine which will give long term morbidity to the player.

In conclusion; acquired biomechanical dysfunction of the cervical spine due to participation in rugby may therefore lead to early degenerative changes. The results of the study indicated a restoration of segmental motion of the cervical spine following the various interventions and this implies normalisation of the joints. Therefore it could be hypothesised that these interventions may prevent degenerative changes of the cervical spine if they are performed on a regular basis. This will however have to be researched in a long-term follow-up study.

7.10 Summary

In this chapter the results of the investigation was given in terms of the aims of the study as outlined in chapter 1. The results of the manual physiotherapy technique (Group 1) and therapeutic exercise programme for the correction of biomechanical dysfunction (Group 2) found to be effective in the correction of the cervical biomechanical dysfunction. The results concerning the safety of the therapeutic exercise programme (Group3) was also provided as well as the results of Group 4, the control group. Subsequently the results of the neck rehabilitation programme were discussed as well as factors which could contribute to the development of

biomechanical dysfunction were discussed. Prevention of spinal cord injuries as well as the prevention of early degeneration of the cervical spine was also addressed.

Chapter 8

Summary, Conclusions and Recommendations

In this chapter a summary of the literature reviewed will be provided as well as a brief review of the empirical study performed for this investigation. The conclusions of the study will then be discussed, followed by recommendations for schoolboy rugby players. The chapter will end with a brief discussion of the limitations of the study.

8.1 Summary

The literature reviewed by the researcher proved to be a challenge since this study investigated evaluation and treatment approaches not previously studied in the management of biomechanical dysfunction in schoolboy rugby players. The researcher therefore reviewed relevant literature and applied the knowledge gained in the development of a therapeutic exercise programme for the correction of biomechanical dysfunction as well as a neck rehabilitation programme, which could be implemented by coaches, healthcare professionals and educators who manage schoolboy rugby players. These programmes were included in a clinical trial forming part of this study.

The principles of physiotherapy have been part of the healing art since the beginning of recorded time. The task of the physiotherapist is to improve an individual's quality of life by restoring normal musculoskeletal function, or minimising dysfunction, as well as preventing disability following disease or injury. A combination of manual physiotherapy, movement training and physical agents are used to resolve a condition. A skilled physiotherapist will apply the appropriate treatment based on scientific and professional knowledge and specialised skills following a thorough assessment of the patient's condition. Assessment is aimed at collecting relevant information pertaining to the patient's condition as well as the patient's living and working environment. More recently the physiotherapist has also become more active in the prevention of injuries as well as in the interception

of degenerative orthopaedic conditions. This is achieved by means of thorough biomechanical assessments and the timely correction of any abnormalities found (Sutcliffe, 2000).

The literature was subsequently reviewed concerning the anatomy and biomechanics of the spine, focussing on the cervical spine. The cervical spine is made up of various tissue types, including connective, nervous and epithelial tissues. These tissues are the building blocks for muscle, bone, cartilage, tendons, ligaments and fascia of the cervical spine.

The term biomechanics describes the science involving the study of biological systems from a mechanical perspective (Hall, 1999:32). The tools of mechanics and the action of forces are used to study the functions of the human body. Biomechanics is a subdivision of kinesiology, the study of human movement (Hall, 1999:3–5).

Biomechanical principles could be used in the prevention and rehabilitation of injuries (McGinnis, 1999:6-12). The various biomechanical principles relevant to the cervical spine of a schoolboy rugby player were discussed and this was then applied to the biomechanical dysfunction found in the schoolboy rugby players.

Biomechanically, the human spine is a remarkable structure that must meet two seemingly contradictory requirements namely the achievement of sufficient stability and the provision of adequate mobility (Danneels & Vanderstraeten, 2004). The movement of the head are executed by the muscles, but the type of movements possible depends on the shape and structure of the cervical vertebrae and the interplay between them (Onan *et al*, 1998). The cervical spine must further protect the vital spinal cord and vertebral arteries whilst still providing sufficient stability and mobility for the head.

It is essential for any human being to move. The endogenous forces acting on the motion segments of the cervical spine, such as the joints, muscles and ligaments surrounding the motion segment, could contribute to the development of biomechanical dysfunction. External forces acting on the cervical spine of a schoolboy rugby player, such as the forces transmitted through the cervical spine

during a scrum or a tackle, are also considered as possible contributing factors in the development of biomechanical dysfunction in the cervical spines of rugby players.

Terminology used in the description of human movement was discussed in great detail with the cervical spine being the pivot of the discussion. The knowledge gained through the literature reviewed on biomechanics and movement of the cervical spine was implemented in the motion segment analysis of the cervical spine using the manual physiotherapy technique investigated for this study. This knowledge was essential in understanding the clinical evaluation technique taught by Rocabado (1999).

The kinematics of cervical flexion and extension movements were also discussed in detail since the x-ray performed included lateral flexion and extension views of the cervical spine. Segmental motion is analysed from these lateral flexion and extension views of the cervical spine. In their study Frobin et al (2002) studied a total number of 137 sets of lateral x-rays with flexion and extension views. The subjects had a mean age of 33 for both genders and a radiologist examined the x-rays and found no pathology. They state that the precise measurement of rotational motion offers a precise tool to investigate and document effects of conservative or operative treatment.

Studies reviewed by the researcher for manual physiotherapy techniques typically use pain as an indicator for determining the outcome of the study. Pain was an exclusion criterion for the current study and the pure correction of biomechanical dysfunction became one of the aims of the study. The group of subjects who reviewed manual physiotherapy were treated on an individual basis with correction of each motion segments held in a dysfunctional position independently.

Physiotherapists have used exercises for the management of neuromusculoskeletal conditions since the profession emerged (Hodges, 2004). For the groups of players who performed the therapeutic exercise programme for the correction of biomechanical dysfunction the aim was to determine the efficacy and safety of the programme. This programme was developed for all schoolboy rugby players independent of whether they had cervical spine biomechanical dysfunction or not.

Such a programme would be ideal for implementation in a team setup where the services of a skilled physiotherapist might not be readily available to the team.

When developing a neck rehabilitation programme, to be implemented following the correction of biomechanical dysfunction, which includes the acquiring of new skills and movement patterns the neuroscientific basis for human movement, motor learning and neuromuscular control should be well understood.

Most movements are learned in early childhood, but the repertoire is increased on a daily basis if so required. According to present knowledge this is possible because each functional motion relies upon perceptuo-motor coordination that involves three major components: the intake of sensory information, the internal coding of this information into a format that is adequate for driving a motor action, and the generation of movements themselves (Jovović *et al*, 1999).

Motor learning is one of the basic principles in physical education and therefore very important in this study since an aim of this study is to educate schoolboy rugby players in the wellbeing of their necks and for each player to take responsibility for himself. Sage (1977) stated that motor learning is fundamental to human life and consists of neural, physical and behaviour components. Hodges (2004) explained the utilisation of motor learning and motor control principles in the development of therapeutic exercise intervention.

Although the general goal of exercises in the management of neuromusculoskeletal conditions has generally aimed at improving movement performance, the strategies used and the specific goals have evolved over time. For example, early intervention for lower back pain focussed on improving the strength and endurance of the trunk muscles, with the basic goal to improve the strength and stability of the spine. More recently exercise interventions have evolved to focus on issues of motor control, rather than primary emphasis on muscle parameters, however the goal essentially remains the same.

A neuromusculoskeletal theoretic approach was used in the development of the neck rehabilitation programme. The basis of each exercise was researched and the effect of

the exercise in terms of neuroscience was well explained. This programme was intended to address all aspects of rehabilitation, thereby maintaining the neck in an optimum condition. Exercise interventions have been refined to encompass motor learning principles to train the nervous system to use the spinal muscles in a manner more akin with normal function (O'Sullivan *et al*, 1997 and Hides *et al*, 2001).

A randomised control trial (RCT) by Jull (2004) suggested a neck rehabilitation programme for patients suffering from acute whiplash. It was proposed that physiotherapy management include a specific multi-modal rehabilitation programme which is based on a programme with proven efficacy for cervical disorders. This should include assurance, education and ergonomic advice, a graded specific therapeutic exercise programme which emphasises restoration of active stabilisation, manual therapy and electrotherapy modalities as indicated. If the subjects presented with deficits in postural control a programme retraining cervico-cephalic sensibility and balance should be added to the rehabilitation programme (Revel *et al*, 1994). Even though the schoolboy rugby players of the current study could not be considered as having an acute neck injury, these basic elements for rehabilitation of the cervical spine as suggested by Jull (2004) were included in the design of their programme.

The literature for each of these elements of a rehabilitation programme was discussed in detail as well as the function of each neck muscle to be trained by this programme. The ultimate goal of this final rehabilitation programme will be to provide the schoolboy rugby player with a programme that could reduce the risk of cervical spinal cord injury or prevent possible early degenerative changes of the cervical spine.

Traditionally the mechanism of injury (MOI) for cervical spinal cord injury are said to be hyper-flexion with or without rotation, and hyperextension (Secin *et al*, 1999 and Scher, 1982). The neck of a tight row forward is estimated to brace 1 to 1.5 tons (Secin, 1999 and Scher 1982). Axial loading and spearing (hitting the opponent with the vertex of the head) have been stated by Torg *et al* (1990) and Noakes and Du Plessis (1996:209) as the MOI in tackle football which includes rugby union, rugby league and American Gridiron football.

Taylor and Coolican (1988) looked at preventative programmes and rule changes to make rugby safer. They reasoned that because there were very few cervical spinal cord injuries in players younger than 14 years of age one could assume that the very flexible immature spine of the adolescent provides a measure of protection against injury. These researchers also stated that no acceptable evidence exists to prove that stronger neck muscles protects against neck injuries. They say that a powerful neck and torso contributes to the forces in rugby union with power scrumming forming part of the game. They state that the mechanism of injury in American football have been studied in great detail and that axial loading was pinpointed as the cause of injury. The current study investigated a rehabilitation programme, developed by the researcher, using cervical circumference of the neck as measurement to measure hypertrophy of the neck muscles as proposed by Scher (1991). A long-term follow up study will be necessary to determine the impact of this rehabilitation programme on cervical spinal cord injuries in schoolboy rugby players.

The possibility that the biomechanical dysfunction found in the schoolboy rugby players could contribute to the early degenerative changes seen in adult rugby players (Scher 1991) was also motivated in detail using relevant reviewed literature. Such a prevention of early degenerative changes could only be proven if these players who participated in this study could be x-rayed five and ten years from now.

For the empirical study three schools with rugby as a school sport were randomly selected to participate in the study. The subjects and the parents or guardians of the subjects were required to sign an informed consent form as a prerequisite for inclusion into the study and the opportunity was afforded each player to ask for clarity on the contents of the ICF as well as to the aims and safety aspects of any of the aspects of the study. One of the schools was selected for investigating the efficacy of the manual physiotherapy technique with 25 players selected for this intervention (Group 1). Another school was selected for performing the therapeutic exercise programme for the correction of biomechanical dysfunction, with one group of 25 players who presented with biomechanical dysfunction of their cervical spines (Group 2) and the other group of 25 players presented with a normal cervical spine (Group3). Twenty-five players from the third selected school formed the control group (Group 4).

The players underwent a thorough a process of physiotherapy evaluation, x-ray investigations and completion of an initial questionnaire prior to the start of the interventions. The interventions studied were a manual physiotherapy treatment technique proposed by Rocabado (1999) for the players of group 1, and a therapeutic exercise programme for the correction of biomechanical dysfunction, developed by the researcher based on the manual physiotherapy technique, performed by Group 2 and 3. The control group did not receive any intervention. The various interventions were followed for a month, after which a second set of x-rays were done. The players of Groups 1, 2 and 3 then proceeded with the neck rehabilitation programme for a period of 12 weeks. On completion of the neck rehabilitation programme the final process, which included x-ray investigation, completion of a final questionnaire and a final physiotherapy assessment, was completed.

A process of x-ray measurements and sorting of data were completed before the biostatistician conducted the statistical analysis.

8.2 Conclusions

This section will contain the conclusions of the study, based on the results as discussed in Chapter 7. The conclusions will be discussed according to the aims as set out in Chapter 1.

8.2.1 Primary Physiotherapeutic Aim: Motion segment analysis using the physiotherapeutic evaluation technique

The evaluation technique used in this study was taught by Rocabado (1999) at a formal training course attended by the researcher. He proposed that a restriction of rotation combined with lateral flexion to the opposite side could be interpreted as a flexion restriction of the particular motion segment. This was the restriction most commonly found in the cervical spines of the schoolboy rugby players evaluated by

the researcher in a previous study (Steyn, 2002). It was therefore assumed that the same flexion restriction would be found in the current study. Since this evaluation technique has not yet been validated through evidence based research, it was decided to test the validity of this evaluation technique during this study.

The results of the previous research project (Steyn, 2002) were confirmed in this study, with the motion segments of the lower cervical spine in particular presenting with a restriction to flexion movement. Theoretically it could therefore be expected that the x-ray measurement of the flexion angle of players evaluated as having cervical spine biomechanical dysfunction should be less than the flexion angle found in the players without biomechanical dysfunction. In determining the validity of the physiotherapy evaluation technique the x-ray measurements for the flexion angle, the extension angle as well as the angle of rotation of the tested motion segments were compared to the physiotherapy biomechanical dysfunction found by the researcher.

The C5/C6 cervical vertebrae level were statistically highly significant with an effect size for the mean flexion angle of $d = 1.08516$. This would suggest that the theory of the movement pattern of rotation with opposite lateral flexion restriction is indeed analogous with a restricted flexion angle x-ray measurement. This provides validity to the theory suggested by Rocabado (1999) for the C5/C6 motion segment. The other motion segments measured had small to moderate statistically significant results, with the C3/C4 motion segment testing the poorest correlation. The measurements for extension angle indicated no comparison and only the C5/C6 motion segments' angle of rotation showed any statistically significant result with an effect size of $d = 0.8099$.

It could therefore be concluded that the physiotherapeutic motion segment analysis technique proposed by Rocabado (1999) is indeed valid in determining biomechanical dysfunction of the cervical spine, but not highly reliable in determining the exact motion segment level of dysfunction. For the physiotherapy profession this result is important since this evaluation technique could be used to evaluate the cervical spine for possible biomechanical dysfunction in a multitude of conditions that could contribute to pain and dysfunction, such as whiplash injury, chronic neck pain etc.

8.2.2 Primary Physiotherapeutic Aim: Manual physiotherapy Technique in the correction of Biomechanical Dysfunction

A manual therapy treatment technique for the correction of the cervical spine biomechanical dysfunction found in this population of schoolboy rugby players was also taught by Rocabado (1999). The detail of this treatment technique was given in chapter 6. The players were treated using this technique until the biomechanical dysfunction was corrected, as tested using the physiotherapy evaluation technique.

The mean flexion angle improved with high statistical significance for C5/C6 and C6/C7 as well as for total flexion of the cervical spine, and moderately for the C3/C4 as well as C4/C5 motion segments. The angles of rotation for the C5/C6 and C6/C7 also showed highly statistically significant improvements. The remaining translation and extension measurements did not improve significantly, as was expected as the physiotherapy evaluation did not find any extension restrictions in the rugby players.

For the physiotherapy profession this is a highly significant finding. In the event of biomechanical dysfunction found in any patient who may be referred for physiotherapy treatment, this provides a technique that could be used to correct the found dysfunction. Correction of dysfunction would then normalise the strain on the particular motion segment and with strengthening of the muscles around the cervical spine the patient will have a more functional neck. This could be beneficial both in the prevention and treatment of neck pain and disability.

8.2.3 Primary Education Aim: Therapeutic Exercise Programme for the correction of Biomechanical Dysfunction

This exercise programme was completed by 25 players with biomechanical dysfunction to test the efficacy of the programme in the correction of biomechanical

dysfunction and by 25 players without biomechanical dysfunction to test the safety of the programme in players without biomechanical dysfunction. The results indicated that the therapeutic exercise programme yielded moderately significant improvements for C5/C6 flexion, C6/C7 flexion and total flexion. The angle of rotation for the C6/C7 motion segment also improved with moderate significance. The remaining measurements showed very small significant improvements.

The therapeutic exercise programme for the correction of biomechanical dysfunction proved to be slightly less effective in the correction of the cervical spine dysfunction than the physiotherapy technique, but clinically could be extremely effective in a team setting where the team does not have access to a skilled physiotherapist for evaluating and treating biomechanical dysfunction in schoolboy rugby players.

The therapeutic exercise programme for the correction of biomechanical dysfunction was found to be safe with only a weak statistically significant improvement in the mean flexion angle as well as the angle of rotation of C6/C7 motion segment. The remainder of the measurements were statistically insignificant. In the final questionnaire completed by the players no subject reported any clinical adverse symptoms resulting from the exercise programme.

It was expected that no change in the measurements of the control group would occur in the 12 weeks between the first and the second sets of x-rays. The only result that were of weak statistical significance was the deterioration in mean flexion angles of the C4/C5 and C5/C6 motion segments as well as a deterioration of weak statistical significance in the angle of rotation of the C5/C6 motion segment.

It could therefore be concluded that even though not statistically significant, a weak deterioration was found in the mean flexion angles of the C4/C5 and C5/C6 motion segments and the angle of rotation of the C5/C6 motion segment. Most of the flexion angles measured showed a negative trend. Clinically this could imply that during a rugby season a progressive deterioration in biomechanical dysfunction takes place. It is therefore very important to start with the correction of biomechanical dysfunction from an early age in the schoolboy rugby player.

It could thus be concluded from these results that the therapeutic exercise programme for the correction of biomechanical dysfunction is both effective in correcting biomechanical dysfunction found in schoolboy rugby players as well as safe for those players without dysfunction, thus this programme could be implemented for all schoolboy rugby players without physiotherapy evaluation or x-rays to test for possible dysfunction. This programme is also extremely cost effective.

8.2.4 Primary Education Aim. The Neck Rehabilitation Programme

Scher (1991) studied x-rays of the cervical spines of people carrying extremely heavy loads on their head in the rural areas of South Africa. He concluded that no degenerative changes could be seen in their cervical spines and suggested that this could be due to the strong stabilising ability of their neck muscles. He suggested that rugby players should improve their neck strength and stability in the same way to stabilise their cervical spines and that the cervical circumference of the neck should be used to test any proposed rehabilitation programme.

The researcher theorised that the players who indicated that they partially or fully complied with the rehabilitation programme would have more statistically significant improvement in cervical circumference than the players with poor compliance to the programme. The results did not support this theory. All the players who completed the rehabilitation programme showed highly statistically significant improvement in cervical circumference, irrespective of the degree of compliance with the rehabilitation programme. As shown in the results the increase in cervical circumference could be considered as the result of the rehabilitation programme and not because of a general increase in weight, since no statistically significant change in the weight of the players could be found.

Therefore it could be concluded that a high degree of compliance with the rehabilitation programme is not necessary for a significant improvement in muscle strength of the neck muscles. This is very positive for the implementation of this programme by all schoolboy rugby players.

Initially the researcher hypothesised that the biomechanical dysfunction should be corrected with the physiotherapy intervention and the therapeutic exercise programme for the correction of biomechanical dysfunction followed during the first month of the study. It was further hypothesised that the neck rehabilitation programme will then maintain this correction. The results did not support this hypothesis. A further improvement in the cervical biomechanical dysfunction was still present following the second set of x-rays, and following the rehabilitation programme.

As with the cervical circumference findings compliance with the rehabilitation programme did change the statistical significance of the outcome in the correction of biomechanical dysfunction. There were no significant difference in results between the players who complied poorly with the programme and the players with better compliance. There was a moderately statistically significant improvement in the mean flexion angles of the C5/C6 and C6/C7 motion segments. The mean total flexion also improved with moderate significance as well as the angles of rotation for the C3/C4 and C4/C5 motion segments. The C5/C6 and C6/C7 angles of rotation decreased with moderate significance to a more normal angle of rotation. No statistically significant change in the extension and translation measurements was found.

It could thus be concluded that the emphasis placed on including various motor learning rudiments in the neck rehabilitation programme, as described by the researcher in the literature review (Chapter 4:92), proved to be highly effective in restoring normal movement patterns and dynamic stability to the cervical spine which indicated cervical spine biomechanical dysfunction. Should these concepts be combined with a form of corrective intervention, such as manual physiotherapy and/or the therapeutic exercise programme for the correction of biomechanical dysfunction the outcome will be clinically increased. These combined programmes would therefore provide the schoolboy rugby player with a comprehensive programme for the correction of biomechanical dysfunction and neck rehabilitation, which may possibly reduce his risk of cervical spinal cord injury as well as possibly prevent early degeneration of his cervical spine.

8.2.5 Secondary Aim: Posture and Biomechanical Dysfunction

It was theorised that the players with poor posture would have an increased incidence of biomechanical dysfunction compared to the players with normal posture. The results of the investigation show an inverted result. Group 3 consist of players without biomechanical dysfunction and the largest statistical significance was found between posture and dysfunction in this group. For Group 1 the significance was strong for only one motion segment and for Group 2, the other group with biomechanical dysfunction, the correlation was weak for only two motion segments.

The conclusion drawn from these results are that there is no correlation between poor posture and the biomechanical dysfunction found in these schoolboy rugby players. Theoretically the reason for this could be that the biomechanical dysfunction found in this population of schoolboy rugby players involves extension of the lower cervical spine and not flexion, as suggested by a forward neck posture, the posture type most common in the schoolboy rugby players.

The various groups compared well to one another as far as the anthropometric measurement were concerned therefore it could be concluded that the results of this study could not have been influenced by the following factors: age, years of participation in rugby, initial weight and initial cervical circumference.

8.2.6 Secondary Aim: Playing position and Biomechanical Dysfunction

According to the literature it could be expected that the forward players would have a higher prevalence for biomechanical dysfunction of their cervical spines due to the loads being placed on the necks of these players during the scrum as well as rucks and mauls. This theory was shared by the majority of players (92%) who completed the initial questionnaire. They stated that forward position players were at greater risk of injuring their necks. This theory was not supported by the results of this study, but

rather confirmed the results of a previous study conducted by the researcher (Steyn, 2002).

The total flexion angle and the total extension angle of the motion segments measured were used. It was expected that the total flexion angle of the forward players would be less than the total flexion angle of the backline players. There were no statistically significant difference in the total flexion or extension angles between the forwards and the backs, the backs had a slightly smaller total flexion angle than the forwards. The forwards and backs were well matched in terms of numbers and mean age.

It could therefore be concluded that there are no statistically significant difference in the occurrence of biomechanical dysfunction of the cervical spine between forward and backline players. This could be due to the fact that biomechanical dysfunction could also develop during the tackling and mauling phases of play, where the backs are also involved frequently.

The manual physiotherapy technique as well as the therapeutic exercise programme for the correction of biomechanical dysfunction was proven to be effective in correction biomechanical dysfunction in the cervical spines of schoolboy rugby players. Any schoolboy rugby player presenting with biomechanical dysfunction of his cervical spine would therefore benefit from these corrective techniques.

8.3 Recommendations

The following recommendations apply to the skilled physiotherapists, the educators and coaches at high schools where rugby is a school sport.

8.3.1 Manual Physiotherapy Evaluation and Treatment Technique

The researcher recommends that all physiotherapists acquire the skills necessary to perform this evaluation technique investigated in this clinical trial as suggested by

Rocabado (1999). For the physiotherapy profession the advantage of having an effective and safe tool that could be utilized in forming a biomechanical picture of the motion segments of the cervical spine is phenomenal. Physiotherapist in South Africa, who has legislated first line practitioner status, are not always in the position to have x-rays of the patient taken on the first consultation and this evaluation technique provides them the opportunity to evaluate the cervical spine objectively prior to the start of treatment. This broadens the toolbox of techniques and approaches for the physiotherapist.

This evaluation technique could be used to evaluate the cervical spine for a possible biomechanical dysfunction in a multitude of conditions that could contribute to pain and dysfunction, such as whiplash injury, chronic neck pain etc. It is well known that the incidence of pain and neurological symptoms originating from the level above and / or below a surgical cervical fusion becoming symptomatic within a couple of years following the fusion is high. It could be theorised that the motion segment above the fusion could be in a position of biomechanical dysfunction. Correcting such dysfunctions as part of the post-surgical treatment regime could possibly reduce the chances of this level becoming symptomatic afterwards.

Not only will this study provide the physiotherapist with a valuable evaluation technique, it will also provide the manual physiotherapist with a treatment technique proven to be highly significant in correcting this specific biomechanical dysfunction found in the cervical spines of schoolboy rugby players in high school. This technique was also suggested by Rocabado (1999) and could be used in any patient who presents with a biomechanical dysfunction. Correcting the biomechanical dysfunction of the motion segments of the cervical spine could be theorised as being the first step in normalising movement pattern of the cervical spine, thereby restoring normal function to the cervical spine. This technique could therefore be studied in a wide variety of conditions where previous clinical trials, not addressing the correction of biomechanical dysfunction, found limited success in their results.

8.3.2 Therapeutic Exercise Programme for the correction of Biomechanical Dysfunction and Neck Rehabilitation Programme

Notwithstanding the fact that the therapeutic exercise programme for the correction of biomechanical dysfunction proved to be less effective in the correction of biomechanical dysfunction than the physiotherapy technique, it is still recommended that this programme be implemented for all schoolboy rugby players. This programme was designed for a team approach comprising coaches, educators and players and not for an individual approach, such as the physiotherapy correction technique. Add to this programme the improvements seen in the correction of biomechanical dysfunction following the neck rehabilitation programme, the combined effect resulted in an improvement that brought the player within normal limits for all the measurements performed.

The role of the school in the implementation of these programmes is of fundamental importance. The success of these programmes is to a large degree dependant on the educator who implements the programmes and motivates the player to comply with the programmes. The experience of the researcher in this study was that the players listen to the coach, since this could affect their position in the team. Thus if the coach emphasises the necessity of compliance with the programmes and strictly enforces these programmes during training, the players will comply. From the completed initial questionnaire the players clearly indicated that they felt that their coaches did not have sufficient knowledge pertaining to neck strengthening exercises. It is accordingly recommended that sufficient time is spent educating the role players who will be implementing these programmes to high schoolboy rugby players, to ensure that the players develop a high confidence in the educator/coach regarding their knowledge of neck strengthening exercises.

It is strongly recommended that no changes be made to the therapeutic exercise programme for the correction of biomechanical dysfunction or the neck rehabilitation programme. These programmes are explained in detail in Chapter 6.

The researcher also recommends that the therapeutic exercise programme for the correction of biomechanical dysfunction as well as the neck rehabilitation programme should be initiated prior to start of the season and that the player should be comfortable with the phase two exercises before participating in any rugby activity. Phase three exercises could be implemented at commencement of the rugby season and as soon as the players can adequately perform the phase three exercises, this level of motor skills should be maintained by maintaining the programme at least once, preferable twice a week for the remainder of the season. These programmes should therefore be implemented as least 8 weeks prior to the start of the season.

It is advised that the exercises performed for phase three of the neck rehabilitation programme be used as a baseline for strength, dynamic stability, motor control and flexibility for all schoolboy rugby players. This baseline may be used for any person who wants to start playing rugby as well as for the return to the game after an extended absence following a neck injury. This is a cost effective test and does not require normative strength values as measured by expensive testing equipment as suggested by Seng et al (2002).

To summarise, these programmes have been proven to be effective and safe for implementation for all schoolboy rugby players based on sound and acceptable research methodology and biostatistical analysis. These programmes are also extremely cost effective compared to available marketed trade name exercise systems. The only equipment required by the player is a tennis ball, one metre length of green Theraband and one metre length of silver Surgical Tubing, costing in present day value terms approximately R 30 – 00.

8.3.3 Normative values for motion segment analysis for schoolboy rugby players.

This study will therefore provide the first normative values for motion segment analysis for schoolboy rugby players. The means of the various x-ray measurements of the final x-rays following correction biomechanical dysfunction as well as the neck rehabilitation programme, for Groups 1, 2 and 3, were used as an indication of the

normal values expected for a schoolboy rugby player. The measurements for the control group (Group 4) were omitted since some of these players had cervical spine biomechanical dysfunction with no intervention to correct this dysfunction.

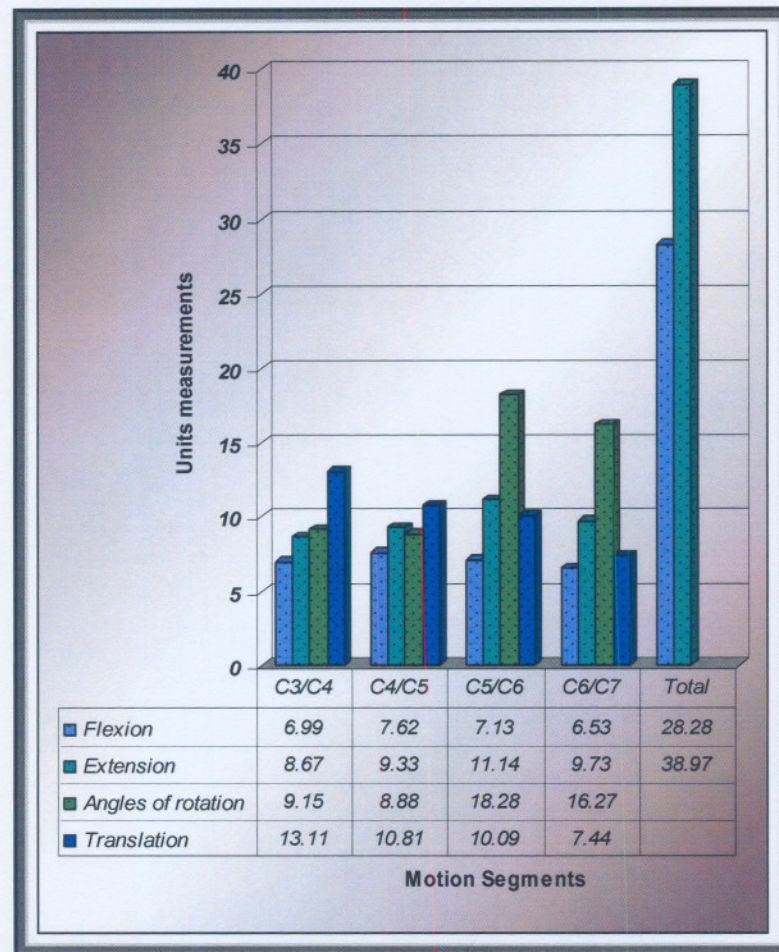


Figure 8.1: Normative values for all the x-ray measurements performed following the neck rehabilitation programme for cervical spine motion segments C3 to C7.

8.3.4 Recommendations for future studies

The scope of this study did not include testing these programmes for the prevention of cervical spinal cord injuries as well as the possible prevention of early degenerative changes of the cervical spine by Scher (1991) in adult rugby players. The researcher

did however hypothesise following the outcome of these programmes that these programmes could aid in the prevention of cervical spinal cord injuries, due to the fact that biomechanical dysfunction was corrected as well as the fact that neck muscle strength improved significantly. It is therefore recommended that an empirical study be conducted where these programmes are implemented as part of the spinal cord injury prevention programme to all schoolboy rugby players and that the incidence of spinal cord injuries be studied following the implementation of these programmes.

A further recommendation for a future study is to follow up with x-rays of these players after 5 and 10 years from this study to compare the findings to the study by Scher (1991), who found early degenerative changes on x-rays of adult rugby players.

8.4 Limitations

The most significant limitation of the study is the fact that this clinical trial could not be considered as a randomised control trial. True randomisation would mean that all the players of a specific school would have to have an equal opportunity of inclusion into the different intervention groups. The problem encountered with this approach was twofold during the pilot study. Firstly all the players wanted to be selected for the group of players who received physiotherapy since this group had a perceived advantage. Compliance was also a major problem, since the various programmes could not be implemented as part of the normal rugby training session, since the timing of the exercises for the various groups was not the same.

As far as the measurements of the x-rays were concerned, the most objective results would have been achieved if image recognition software could have been used to recognise the landmarks used on the vertebrae from which the measurements were then made. No such programme is currently commercially available in South Africa and no funding was available to the researcher for developing such a programme.

REFERENCES

- ABBOT, J.H., 2004. The nexus of clinical examination and outcome research. (*In 8th International Federation of Orthopaedic Manipulative Therapists' conference held in Cape Town, South Africa on 21 to 26 March 2004. p. 85-89*)
- ADAMS, M.A. & HUTTON, W.C. 1982. Prolapsed intervertebral disc. A hyperflexion injury. *Spine*, 7(3):184.
- AHMED, A.M., DUNCAN, N.A. & BURKE, D.L. 1988. The effect of facet geometry on the axial torque-rotation response of lumbar motion segments. *Trans. Orthop. Res. Soc.*, Atlanta.
- ALARANTA, H., HURRI, H., HELIÖVAARA, M., SOUKKA, A. & HARJU, R. 1994. Flexibility of the spine: Normative values of goniometric and tape measurements. *Scand J Rehabil Med*. 26:147-54.
- ALBRIGHT, T.D., KANDEL, E.R. & POSNER, M.I. 2000. Cognitive neuroscience. *Current Opinion in Neurobiology*, 10(5):612-624, Oct.
- ALWAY, S.E., MacDOUGALL, D., SALE, G, et Al. 1988. Functional and structural adaptations in skeletal muscle of trained athletes. *Journal of Applied Physiology*, 64:1114.
- ANDERSEN, R.A., SNYDER, L.H., BRADLEY, D.C. & XING, J. 1997. Multimodal representation of space in the posterior parietal cortex and its use in planning movements. *Annu Rev Neurosci* 20, pp. 303-330.
- ANDERSON, J.R. 1982. Acquisition of cognitive skill. *Psychological Review* 89, pp. 369-406.
- ARMSTRONG, N. & WELSMAN, J. 1997. Young People & Physical Activity. Oxford : Oxford University Press. 158p

ARUIN, A.S. & LATASH, M.L. 1995. Directional specificity of postural muscles in feed-forward postural reactions during fast voluntary arm movements. *Exp Brain Res* **103**, pp. 323-332.

AUSTRALIAN BUREAU OF STATISTICS (ABS). 2000a. Children's participation in cultural and leisure activities. *Report 4901.0*. Canberra, Australia Bureau of Statistics.

AUSTRALIAN BUREAU OF STATISTICS (ABS). 2000b. Use of the internet by householders. *Report 8147.0*. Canberra, Australia Bureau of Statistics.

BADDELEY, A.D. 1986. Working memory. Oxford University Press, Oxford.

BANDY, W., LOVELACE-CHANDLER, V., BRANDY, B. et al. 1990. Adaptation of skeletal muscle to resistance training. *Journal of Orthopaedic and Sports Physical Therapy*, 12(6):248-55.

BANDY, W.D. & IRION, J.M. 1994. The effect of time of static stretch on the flexibility of the hamstring muscles. *Physical Therapy*, 74:845-52.

BAUZE, R.J. & ARDRAN, G.M. 1978. Experimental production of forward dislocation in the human cervical spine. *J Bone Joint Surg.* **45B**:21.

BELL, G.H., DUNBAR, O., BECK, J.S. & GIBB, A. 1973. Variation in strength of vertebrae with age and their relation to osteoporosis. *Calcif. Tissue Res.*, 1:75.

BERGE, J., MARQUE, B. & VITAL, J.M. 1999. Age-Related changes in the Cervical Spines of Front-Line Rugby Players. *Am J Sports Med* **27**, pp. 422-429.

BERNHARDT, P., WILKE, H.J., WENGER, K.H. JUNGKUNZ, B., BÖHM, A. & CLAES, L.E. 1999. Multiple muscle force simulation in axial rotation of the cervical spine. *Clinical Biomechanics*, 14:32-40.

BEXANDER, C.S.S., MELLOR, R. & HODGES, P.W. 2004. Effect of gaze direction on neck muscle activity during cervical rotation. (*In 8th International Federation of Orthopaedic Manipulative Therapists' conference held in Cape Town, South Africa on 21 to 26 March 2004. p. 30*)

BILLIS, E.V., FOSTER, N.E. & WRIGHT, C.C. 2003. Reproducibility and repeatability: errors of three groups of physiotherapists in locating spinal levels by palpation. *Manual Therapy*, 8(4):223-232, Nov.

BioMedNet. 2003. Medline search. [Web:] <http://research.bmn.com/medline> [Date of access May 2003 – April 2004].

BIZZI, E., ACCORNERO, N. CHAPPLE, W. & HOGAN, N. (1984). Posture control and trajectory formation during arm movement. *J. Neurosci* 4, pp. 2738-2744.

BIZZI, E., FRERDINATO, A. & MUSSA-IVALDI, F.A. 1998. Neural basis of motor control and its cognitive implications. *Trends in Cognitive sciences*, 2(3):97-102, Mar.

BLACKBURN, T. & VOIGHT, M. 1995. Single leg distance: Development of a reliable testing procedure. *Proceedings of the 12th International Congress of the World Confederation for Physical Therapy*.

BLOOMFIELD, J., ACKLAND, T.R. & ELLIOTT, B.C. 1994. Applied Anatomy and Biomechanics in sport. Melbourne : Blackwell Scientific Publications. 374 p.

BOGDUK, N. & MERCER, S. 2000. Biomechanics of the cervical spine. I: Normal kinematics. *Clinical Biomechanics*, 15(9):633-648, Nov.

BOGDUK, N. & YOGANANDAN, N. 2001. Biomechanics of the cervical spine Part 3: minor injuries. *Clinical Biomechanics*, 16(4):267-275.

BRASHERS-KRUG, T., SHADMEHR, R. & BIZZI, E. 1996. Consolidation of human motor memory. *Nature* 383, pp. 252-255.

- BRAULT, J.R., SIEGMUND, G.P. & WHEELER, J.B. 2000. Cervical muscle response during whiplash: evidence of a lengthening muscle contraction. *Clinical Biomechanics*, 15(6):426-435, Jul.
- BREIG, A.L.F. 1960 . *Biomechanics of the central nervous system*. pp 23,24 & 47.
- BRINCKMANN, P. 1986. Injury of the annulus fibrosus and disc protrusions. *Spine*, 11:149.
- BROWN, T., HANSON, R. & YORRA, A. 1957. Some mechanical tests on the lumbo-sacral spine with particular reference to the intervertebral discs. *J. Bone Joint Surg.*, 39A:1135. (*An important study of the physical behavior of the intervertebral disc under many different conditions of loading.*)
- BUONOMANO, D.V. & MERZENICH, M.M. 1998. Cortical plasticity: from synapses to maps. *Annu Rev Neurosci* 21, pp. 149-186.
- BURKE, D.G., CULLIGAN, C.J. & HOLT, L.E. 2000. The theoretical basis of proprioceptive neuromuscular facilitation. *Journal of Strength and Conditioning Research*, 14(4):496-500.
- BUTLER, D.S. 2000. The sensitive nervous system. Adelaide : Noigroup Publications. 431 p.
- BULTER, D.S. & MOSELEY, G.L. 2003. Explain pain. Adelaide : Noigroup Publications. 129 p.
- CHAPMAN, E.A., DE VRIES, H.A. & SWEZEY, R. 1972. Joint stiffness: Effect of exercise on young and old men. *Journal of Gerontology*, 27:218.
- CHIMURA, N., SWANIK, K.A., SWANIK, C.B. & STRAUB, S. 2002. Effects of plyometric training on muscle activation strategies and performance in female athletes. *Journal of Athletic Training*, 37(2):S19.

CLARK, E.J., BURGESS, R.C., CHAPIN, J.W. & LIPSCOMB, W.T. 1985. Role of intramuscular receptors in the awareness of limb position. *Journal of Neurophysiology* 54(6):1529-40.

COHEN, J. 1988. Statistical power analysis for the behavioural sciences. (2nd edition). Erlbourn : Hillside NY.

COHEN, N.P., FOSTER, R.J. AND MOW, V.C. 1998. Composition and dynamics of articular cartilage: structure, function and maintaining healthy state. *Journal of sports physical therapy*, 28(4):203-215.

COLEBATCH, J.G & McCLOSKEY, D.I. 1987. Maintenance of constant arm position or force: Reflex and volitional components in man. *Journal of Physiology*, 386:247-61.

COPPIETERS, M.W., KNOX, J.J. & HODGES, P.W. 2004. Eccentric intra-orbit eye positions reduce postural control of the neck. (*In* 8th International Federation of Orthopaedic Manipulative Therapists' conference held in Cape Town, South Africa on 21 to 26 March 2004. p. 28)

CRESSWELL, A.G., GRUNDSTROM, H. & THORSTENSSON, A. 1992. Observations on intra-abdominal pressure and patterns of abdominal intra-muscular activity in man. *Acta Physiol Scand* 144, pp. 336-341.

DAI, L., CHENG, P., TU, K., XU, Y. AND ZHANG, W. 1992. The stress distribution of the lumbar spine and disc degeneration. *Clinical medical science journal*, Sep. 7:166-8.

DANNEELS, L. & VANDERSTRAETEN, G. 2004. Evaluation of functional spinal stability. (*In* 8th International Federation of Orthopaedic Manipulative Therapists' conference held in Cape Town, South Africa on 21 to 26 March 2004. p. 19)

DAVIDSON, R.M. 1987. Schoolboy rugby injuries, 1969 – 1986. *Medical journal of Australia*, 147(3):119-120.

De DEYNE, P.G. 2001. Application of passive stretch and its implications for muscle fibers. *Physical Therapy*, 81(2):819-27.

DOYA, K. 2000. Complementary roles of basal ganglia and cerebellum in learning and motor control. *Curr Opin Neurobiol* 10, pp. 732-739.

DUDLEY, G.A. & FLECK, S.J. 1987. Strength and endurance training: Are they mutually exclusive? [Review] *Sports Medicine*, 4(2):79.

DVORAK, J., PANJABI, M.M., NOVOTNY, J.E. AND ANTINNES, J.A. 1991. In vivo flexion / extension of the cervical spine. *Journal orthopaedic research*, 9:828-34.

DYHRE-POULSEN, P., SIMONSEN, B. & VOIGT, M. 1991. Dynamic control of muscle stiffness and H reflex modulation during hopping and jumping in man. *Journal of Physiology*, 437:287-304.

ENTYRE, B.R. & LEE, E.J. 1988. Chronic and acute flexibility of men and women using three different stretching techniques. *Research Quarterly for Exercise and Sport*, 59:222-28.

FALLA, D., JULL, G., RAINOLDI, A. & MERLETTI, R. 2004. Neck flexor muscle fatigue is side specific in patients with unilateral neck pain. *European Journal of Pain* 8(1), pp. 71-77.

FARFAN, H.F. 1973. Mechanical disorders of the Low Back. Philadelphia. Lea & Febiger. (*Biomechanical studies conducted by the author and his associates are presented well together with his hypothesis of disc degeneration due to mechanical factors.*)

FAULKNER, J.A., BROOKS, S.V. AND OPITECK, J.A. 1993. Injury to skeletal muscle fibers during contractions: conditions of occurrence and prevention. *Physical therapy*, 73: 911-921.

FEIPEL, V., RONDELET, B., LePALLEC, J.P. & ROOZE, M. 1999. Normal global motion of the cervical spine: an electrogoniometric study. *Clinical Biomechanics*, 14(7):462-470, Aug.

FELDMAN, A.G. 1966. Functional tuning of the nervous system with control of movement or maintenance of a steady posture: 3. Mechanographic analysis of execution by arm of the simplest motor tasks. *Biophysics* 11, pp. 766-775.

FENELON, V.S., CASASNOVAS, B., SIMMERS, J. & MEYRAND, P. 1998. Development of rhythmic pattern generators. *Curr Opin Neurobiol* 8, pp. 705-709.

FRANKEL, H. 1969. The value of postural reduction in the initial management of closed injuries of the spine with paraplegia and tetraplegia. *Paraplegia* 7, pp. 179-192.

FROBIN, W., LEIVSETH, G., BIGGEMANN, M. & BRINCKMANN, P. 2002. Sagittal plane segmental motion of the cervical spine. A new precision measurement protocol and normal motion data of healthy adults. *Clinical Biomechanics*, 17(1):21-31, Jan.

GARRAWAY, M. AND MACLEOD, D. 1995. Epidemiology of rugby football injuries. *The lancet*, 345: 1485-1487.

GEORGOPOULOS, A.P., ASHE, J., SMYRNIS, N. & TAIRA, M. 1992. The motor cortex and the coding of force. *Science* 256, pp. 1692-1695.

GEORGOPOULOS, A.P., CAMINITI, R., KALASKA, J. & MASSEY, J.T. 1983. Spatial coding of movement: a hypothesis concerning the coding of movement direction by motor cortical populations. *Exp. Brain Res. Suppl.* 7, pp. 327-336.

GEORGOPOULOS, A.P., KALASKA, J.F., CAMINITI, R. & MASSEY, J.T. 1982. On the relations between the direction of two-dimensional arm movements and cell discharge in primate motor cortex. *J. Neurosci* 2, pp. 1527-1537.

GHILARDI, M., GHEZ, C., DHAWAN, V., MOELLER, J., MENTIS, M., NAKAMURA, T., ANTONINI, A. & EIDELBERG, D. 2000. Patterns of regional brain activation associated with different forms of motor learning. *Brain Research*, 871(1):127-145.

GIFFIN, J.R. & STANISH, W.D. 1993. Overuse tendonitis and rehabilitation. *Canadian family physician*, 39: 1762-1769.

GILLET, H. 1968. *Belgian Chiropractic research notes*. 7th Edison 1968. p 46.

GOEL, V.K. & CLAUSEN, J.D. 1998. Prediction of load sharing among spinal components of a C5-C6 motion segment using the finite element approach. *Spine*, Mar. 23:684-91.

GORDON, J., GHILARDI, M.F., & GHEZ, C. 1995. Impairments of reaching movement in patients without proprioception. I. Spatial errors. *Journal of Neurophysiology*, 73:347-360.

GOSCH, H.H., GOODING, E. & SCHNEIDER, R.C. 1972. An experimental study of cervical spine and cord injuries. *J. Trauma*. 12:570. (*One of the most important and informative studies on the biomechanics of spine trauma.*)

GOSSELIN, G., RASSOULIAN, H. & BROWN, I. 2004. Effects of neck extensor muscle fatigue on balance. *Clinical Biomechanics*, Article in Press, Corrected Proof, Mar.

GRACOVETSKY, S. & FARFAN, 1986 The optimum spine. *Spine*, 11:543-73.

GRAFTON, S.T., MAZZIOTTA, J.C., PRESTY, S., FRISTON, K.J., FRACKOWIAK, R.S. & PHELPS, M.E. 1992. Functional anatomy of human

procedural learning determined with regional cerebral blood flow and PET. *J Neurosci* **12**, pp. 2542-2548.

GRATTON, G. 1997. Attention and probability effects in the human occipital cortex: an optical imaging study. *Neuroreport* **8**, pp. 1069-1087.

GRAZIANO, M.S., YAP, G.S. & CROSS, C.G. 1994. Coding of visual cortex exhibit inter-columnar synchronization which reflects global stimulus properties. *Nature* **338**, pp. 1054-1057.

GRIGG, P. 1994. Peripheral neural mechanisms in proprioception. *Journal of Sport Rehabilitation*, 3:1-17.

GRILLNER, S., DELIAGINA, T., EKEBERG, O., EL MANIRA, A., HILL, R.H., LANSNER, A., ORLOVSKY, G.N. & WALLEN, P. 1995. Neural networks that coordinate locomotion and body orientation in lamprey. *Trends Neurosci* **18**, pp. 270-280.

GROSS, A.R., AKER, P.D., GOLDSMITH, C.H. & PELSO, P. 1996. Conservative management of neck disorders. A systematic overview and meta-analysis. *Online Journal of Clinical Trials Doc.* No. 200-201.

HAGGARD, P. & MAGNO, E. 1999. Localising awareness of action with transcranial magnetic stimulation. *Exp. Brain Res* **127**, pp. 102-107.

HALL, S.J. 1999. Basic Biomechanics. 3rd ed. Boston : McGraw-Hill International Editions. 577 p.

HALSBAND, U. & FREUND, H.J. 1993. Motor learning. *Curr Opin Neurobiol* **3**, pp. 940-949.

HEYES, C. 2001. Causes and consequences of imitation. *Trends in Cognitive Sciences*, 5(6):253-261, Jun.

HIDES, J., JULL, G. & RICHARDSON, C. 2001. Long term effects of specific stabilizing exercises for first episode low back pain. *Spine*, 26(11)E243-E248.

HIKOSAKA, O., NAKAMURA, K., SAKAI, K. & NAKAHARA, H. 2002. Central mechanisms of motor skill. *Current Opinion in Neurobiology*, 12(2):217-222, Apr.

HIKOSAKA, O., RAND, M.K., MIYACHI, S. & MIYASHITA, K. 1995. Learning of sequential movements in the monkey- process of learning and retention of memory. *J Neurophysiol* 74, pp. 1652-1661.

HIRSCH, C. 1955. The reaction of intervertebral discs to compression forces. *J. Bone Joint Surg.* 37A:1188.

HODGES, P.W. 2004. Therapeutic exercises: Research to clinical practice. (In 8th International Federation of Orthopaedic Manipulative Therapists' conference held in Cape Town, South Africa on 21 to 26 March 2004. p. 159-161)

HODGES, P.W., CRESSWELL, A.G., DAGGFELDT, K. & THORSTENSSON, A. 2001. Three dimensional preparatory trunk motion precedes asymmetrical upper limb movement. *Gait & Posture*, 11(2):92-101, Apr.

HODGES, P.W., CRESSWELL, A.G. & THORSTENSSON, A. 1999. Preparatory trunk motion accompanies rapid upper limb movement. *Exp Brain Res* 124, pp. 69-79.

HODGES, P.W. & RICHARDSON, C.A. 1997. Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. *Exp Brain Res* 114, pp. 362-370.

HODGSON, V.R. & THOMAS, L.M. 1980. Mechanisms of cervical spine injury during impact to the protected head. *Proceedings of the 24th Stapp Car Crash Conference*, 17-42.

HOLM, S., INDAHL, A. & SOLOMONOW, M. 2002. Sensorimotor control of the spine. *Journal of Electromyography and Kinesiology* 12(3), pp. 219-234.

HOLMSTRÖM, E.B., LINDELL, J. & MORITZ, U. 1992. Low back and neck/shoulder pain in construction workers: Occupational workload and psychosocial risk factors. Part 2: Relationship to neck and shoulder pain. *Spine*. 17:672-7.

HORAN, F.T. 1984. Injuries to the cervical spine in schoolboys playing rugby football (Editorial). *Journal of Bone and Joint Surgery*, 66-B(4):470-471.

HUDSPETH, A.J. & LOGOTHETIS, N.K. 2000. Sensory systems. *Current Opinion in Neurobiology*, 10(5):631-641, Oct.

HUMPHREY, L.D. 1981. Flexibility. *Journal of Physical Education, Recreation of Dance*, 52:41.

IHARA, H. & NAKAYAMA, A. 1986. Dynamic joint control training for knee ligament injuries. *American Journal of Sports Medicine*, 14(4):309-15.

ITO, M. (1993). Synaptic plasticity in the cerebellar cortex and its role in motor learning. *Can J Neurol Sci. Suppl* 3, S70-S74.

JAKOET, I. 2002. Contrast injuries in schoolboy rugby. (In: South African Sports Medicine Association. Papers read at the SASMA congress held in Johannesburg in 2002).

JONES, M.A., 2004. Balancing the outcome in research. (In 8th International Federation of Orthopaedic Manipulative Therapists' conference held in Cape Town, South Africa on 21 to 26 March 2004. p. 1-5)

JORDAAN, R. 2004. Pilot study to determine risk factors, which may predispose the adolescent to low back pain. (In 8th International Federation of Orthopaedic Manipulative Therapists' conference held in Cape Town, South Africa on 21 to 26 March 2004. p. 21)

JOVOVIĆ, M., JONIĆ, S. & POPOVIĆ, D. 1999. Automatic synthesis of synergies for control of reaching – hierarchical. *Medical Engineering & Physics*, 21(5):329-341, Jun.

JULL, G. 2000. Deep cervical flexor muscle dysfunction in whiplash. *Journal of Musculoskeletal Pain*, 8 (½), pp. 143-154.

JULL, G. 2004. Balancing the outcomes in management of cervical disorders: Research to clinical practice. (In 8th International Federation of Orthopaedic Manipulative Therapists' conference held in Cape Town, South Africa on 21 to 26 March 2004. p. 68-71)

JULL, G., TROTT, P., POTTER, H., ZITO, G., NIERE, K., EMBERSON, J., HARSCHNER, I. & RICHARDSON, C. 2002. A randomised controlled trial of physiotherapy management for cervicogenic headache. *Spine* 27 17, pp. 1835-1843.

KAIGLE, A.M., HOLM, S.H. AND HANSSON, T.H. 1997. 1997 Volvo award winner in biomechanical studies. Kinematic behavior of the porcine lumbar spine: a chronic lesion model. *Spine*, Dec. 22:2796-806.

KALASKA, R.A., SCOTT, S.H., CISEK, P. & SERGIO, L.E. 1997. Cortical control of reaching movements. *Curr Opin Neurobiol* 7, pp. 849-859.

KALTENBORN, F.M., 1993 The spine. Second edition. Oslo, Norway : Olaf Norlis bokhandel. p 289.

KAPANDJI, I.A. 2002. The physiology of joints. Volume 3, the trunk and vertebral column. Edinburgh, London : Churchill Livingstone. p 251.

KAWATO, M., FURAWAKA, K. & SUZUKI, R. 1987. A hierarchical neural network model for the control and learning of voluntary movements. *Boil. Cybern* 56, pp. 1-17.

KAZARIAN, L.E. 1975. Creep characteristics of the human spinal column. *Orthop. Clin. North Am.* 6:3.

KELLER, T.S., HANSSON, T.H., ABRAM, A.C., SPENGLER, D.M. & PANJABI, M.M. 1989. Regional variations in the compressive properties of lumbar vertebral trabeculae: effects of disc degeneration. *Spine*. 14:1012.

KENDALL, F.P., MCCREARY, E. AND PROVANCE, P.G. 1993. Muscles: testing and function. 4th ed. Baltimore, Md. : Williams & Wilkins. P 451.

KEMPER, H.C.G. 2000. Role of the pediatric exercise scientist in physical education, sports training and physiotherapy. *International journal sports medicine*, 21(2): S118-S124.

KETTLER, A., HARTWIG, E., SCHULTHEIB, M., CLAES, L. & WILKE, H.J. 2001. Mechanically simulated muscle forces strongly stabilize intact and injured upper cervical spine specimens. *Journal of Biomechanics*, 35(3):339-346, Mar.

KEW, T., NOAKES, T.D., ROUX, C., KETTLES, A.N., GOEDEKE, R.E., NEWTON, D.A. AND SCHER, A.T. 1991. A retrospective study of spinal cord injuries in Cape Province rugby players, 1963-1989. *South African medical journal*, 80: 127-133.

KING, A.I., PRASAD, P. & EWING, C.L. 1975. Mechanism of spinal injury due to caudocephalad acceleration. *Orthop. Clin. North Am.* 9:16.

KING, M. 2000. Core stability: Creating a foundation for functional rehabilitation. *Athletic Therapy Today*, 5(2):6.

KOSKIMIES, K., SUTINEN, P., AALTO, H., STARCK, J., TOPPILA, E., HIRVONEN, T., KAKSONEN, R., ISHIZAKI, H., ALARANTA, H. & PYYKKO, I. 1997. Postural stability, neck proprioception and tension neck. *Acta Otolaryngol. (Stockh)* 529, pp. 95-97.

KRAEMER, W.J., DUNCAN, N.D. & VOLEK, J.S. 1998. Resistance training and elite athletes: Adaptation and program considerations. *Journal of Orthopaedic and Sports Physical Therapy*, 28(2):110.

KRAG, M.H., SEROUSSI, R.E., WILDER, D.G. & POPE, H.M. 1987. Internal displacement distribution from in vitro loading of human thoracic and lumbar spinal motion segments: experimental results and theoretical predictions. *Spine*. 12(10):1001.

KUMARESAN, S., YOGANANDAN, N. & PINTAR, F.A. 1998. Finite element modelling approaches of human cervical spine facet joint capsule. *Journal of Biomechanics*, 31:371-376.

LAUREN, H., LUOTO, S., ALARANTA, H., TAIMELA, S., HURRI, H. & HELIOVAARA, M. 1997. Arm Motion Speed and Risk of Neck Pain. *Spine*, 22(18):2094-2099.

LEE, A.J., GARRAWAY, W.M., HEPBURN, W. & LAIDLAW, R. 2001. Injuries of rugby players' subsequent health and lifestyle: beginning a long term follow up. *British journal of sports medicine*, 35: 38-42.

LEES, A. 1999. Biomechanical assessment of individual sports for improved performance. *Sports medicine*, Nov: 28(5): 299-305.

LIBET, B. 1985. Unconscious cerebral initiative and the role of conscious will in voluntary action. *Behavioral and Brain Sciences*, 8:529-566.

LLOYD, D. 1946. Facilitation and inhibition of spinal motoneurons. *Journal of Neurophysiology*, 9:421.

LOEB, G.E. 1993. The distal hindlimb musculature of the cat: interanimal variability of locomotor activity and cutaneous reflexes. *Experimental Brain Research*, 96:125-140.

LORENZ, M.,PATWARDHAN, A. & VANDERBY, R. 1983. Load-bearing characteristics of lumbar facets in normal and surgically altered segments. *Spine*. 8:122.

LOW, J. & REED, A. 1997. Basic biomechanics explained. Butterworth-Heinemann : Oxford. p 271.

LUOTO, S., HURRI, H. & ALARANTA, H. 1995. Reaction time in patients with chronic low-back pain. *Eur J Phys Med Rehabil*. 5:47-50.

MAGEE, D.J., 1997 Orthopedic physical assessment. Third edition. Philadelphia, Pa : W.B. Saunders. P 805.

MAGILL, R.A. 1993. Motor learning: Concepts and applications. (fourth ed.). Brown & Benchmark, Wisconsin.

MAIR, S., SEABER, A.V., GLISSON, R.R. & GARRET, W.E. 1996. The role of fatigue in susceptibility to acute muscle strain injury. *American Journal of Sports Medicine*, 24(2):137-43.

MARKOLF, K.L. & MORRIS, J.M. 1974. The structural components of the intervertebral disc. *J. Bone Joint Surg*. 54A:511. (*A thorough examination of the stiffness properties of the thoracic and lumbar motion segments of the spine.*)

MAROON, J.C. 1981. Catastrophic neck injuries from football in Western Pennsylvania. *Physician and Sportsmedicine*, 9(11):83-86.

MAXWELL, J.P., MASTERS, R.S.W. & EVES, F.F. 2003. The role of working memory in motor learning and performance. *Consciousness and Cognition*, 12(3):376-402, Sep.

McCARTHY, P.W., OLSEN, J.P. & SMEBY, I.H. 1997. Effects of contract – relax stretching procedures on active range of motion of the cervical spine in the transverse plane. *Clinical Biomechanics*, 12(3):136-138.

McCLURE, P., SIEGLER, S. AND NOBILINI, R. 1998. Three-dimensional flexibility characteristics of the human cervical spine in vivo. *Spine*, Jan. 15 23:2 216-23.

McCOMAS, A. 1994. Human neuromuscular adaptations that accompany changes in activity. *Medicine and Science in Sports Exercise*, 26(12):1498-1509.

McGINNIS, P.M. 1999. Biomechanics of sport and exercise. New York : Human Kinetics. p 406.

McCOY, G.F., PIGGOT, J. McAFEE, A.L. & ADAIR, I.V. 1984. Injuries to the cervical spine in schoolboy rugby football. *Journal of Bone and Joint Surgery*, 66-B(4):500-503.

MELVILL-JONES, G.M. & WATT, G.D. 1971. Observations of the control of stepping and hopping in man. *Journal of Physiology*, 219:709-27.

MERCER, S. & BOGDUK, N. 2001. Joints of the cervical vertebral column. *Journal orthopaedic sports physical therapy*, Apr. 31:174-82.

MICHEL, L.J. AND RISEBOROUGH, E.M. 1974. The incidence of injuries in rugby football. *Journal of sports medicine and physical fitness*, 2: 93-98.

MILNER, B., SQUIRE, L.R. & KANDEL, E.R. 1998. Cognitive neuroscience and the study of memory. *Neuron* 3, pp. 3445-3468.

MITCHELL, J. 1994. The Intervertebral joints II: The Facet Joints. *The South African Journal of Physiotherapy*, 50(1):11-14, Feb.

MONFILS, M.H. & TESKEY, G.C. 2004. Skilled-learning-induced potentiation in rat sensorimotor cortex: a transient form of behavioural long-term potentiation. *Neuroscience*, 125(2):329-336, Jan.

MOORE, A. & JULL, G. 2003. Clinical Guideline Developments. *Manual Therapy*, 8(4):193-194, Nov.

MORGAN, D.L. 1977. Separation of active and passive components of short-range stiffness of muscle. *American Journal of Physiology*, 32(1):45-9.

MORONEY, S.P., SCHULTZ, A.B., MILLER, J.A. AND ANDERSSON, G.B. 1988. Load-displacement properties of lower cervical spine motion segments. *Journal biomechanics*, 21:769-79.

MOSBY'S. 2002 (*ed*). Mosby's medical, nursing and allied health dictionary. St. Louis, Mo. : Mosby – Year Book, Inc, 1973 p.

MOSELEY, G.L. 2004. Understanding the effect of virtual and imagined movement in CRPS1 – integrating clinical findings with neuroanatomical data. (*In 8th International Federation of Orthopaedic Manipulative Therapists' conference held in Cape Town, South Africa on 21 to 26 March 2004. p. 43*)

MUSCOLINO, J.E. & CIPRIANI, S. 2004a. Pilates and the “powerhouse”-I. *Journal of Bodywork and Movement Therapies*, 8(1):15-24, Jan.

MUSCOLINO, J.E. & CIPRIANI, S. 2004b. Pilates and the “powerhouse”-II. *Journal of Bodywork and Movement Therapies*, 8(2):122-130, Apr.

NACHEMSON, A. & EVANS, J. 1968. Some mechanical properties of the third lumbar inter-laminar ligament. *J. Biomech.* 1:211.

NAITO, E., KOCHIYAMA, T., KITADA, R., NAKAMURA, S., MATSUMURA, M., YONEKURA, Y. & SADATO, N. 2002. Internally simulated movement sensations during motor imagery activate cortical motor areas and the cerebellum. *J. Neurosci* 22, pp. 3683-3691.

NAKAMURA, K., SAKAI, K. & HIKOSAKA, O. 1999. Effects of local inactivation of monkey medial frontal cortex in learning of sequential procedures. *J Neurophysiol* **82**, pp. 1063-1068.

NATHAN, M., GOEDEKE, R. AND NOAKES, T.D. 1983. The incidence and nature of rugby injuries at one school during the 1982 rugby season. *South African medical journal*, 64: 132-137.

NCHS (USA NATIONAL CENTER FOR HEALTH STATISTICS). 2000. Healthy people 2010: Understanding and improving health. 2nd edition. Hyattsville, MD, USA Department of Health and Human Services, Centres for Disease Control and Prevention.

NIGG, B.M. 1985. Biomechanics, load analysis and sports injuries in the lower extremities. *Sports medicine*, 2: 367-379.

NIGHTINGALE, R.W., CAMACHO, D.L., ARMSTRONG, A.J., ROBINETTE, J.J. & MYERS, B.S. 2000. Inertial properties and loading rates affect buckling modes and injury mechanisms in the cervical spine. *Journal of Biomechanics*, 33(2):191-197, Feb.

NIGHTINGALE, R.W., McELHANEY, J.H., RICHARDSON, W.J. & MYERS, B.S. 1996. Dynamic Responses of the head and cervical spine to axial impact loading. *J. Biomechanics*, 29(3):307-31.

NOAKES, T. 2004. The role of the brain in the integration of the response to exercise and to training. (In 8th International Federation of Orthopaedic Manipulative Therapists' conference held in Cape Town, South Africa on 21 to 26 March 2004. p. 162-165).

NOAKES, T.D. & DU PLESSIS, M. 1996. Rugby without risk: a practical guide to the prevention and treatment of rugby injuries. Pretoria : J.L. van Schaik, p 351.

NOAKES, T.D. & JAKOET, I. 1995. Spinal cord injuries in rugby union players. *British medical journal*, 310:1345-1346.

NOAKES, T.D., JAKOET, I. AND BAALBERGEN, E. 1999. An apparent reduction in the incidence and severity of spinal cord injuries in schoolboy rugby players in the western Cape since 1990. *South African medical journal*, 89:540-5.

NOBLE, C. 1988. Safety in rugby. *Journal of the South African Sports Medicine Association*, 1(1):2.

NOYES, F.R., DELUCAS, J.L. & TORVIK, P.J. 1974. Biomechanics of anterior cruciate ligament failure: an analysis of strainrate sensitivity and mechanisms of failure in primates. *J. Bone Joint Surg.* 56A:236. (*Description of experimental finding that the ligaments have higher strength when tested at higher speeds.*)

NUSHOLTZ, G.S., HUELKE, D.S., LUX, P., ALEM, N.M. & MONTALVO, F. 1983. Cervical spine injury mechanisms. Proc. 27th STAPP car crash conference, *Society of Automotive Engineers*. Warrendale, PA. P 275

O'BRIEN, CP. 1996. "Rugby neck": Cervical degeneration in two front row Rugby Union players. *Clinical journal of sport medicine*, 6:56-59.

ONAN, O.A., HEGGENESS, M.H. & HIPPI, J.A. 1998a. A Motion Analysis of the Cervical Facet Joint. *Spine*, 23(4):430-439.

ONAN, O.A., HIPPI, J.A. & HEGGENESS, M.H. 1998b. Use of computed tomography image processing for mapping of human cervical facet surface geometry. *Medical Engineering & Physics*, 20(1):77-81, Apr.

O'SULLIVAN, P.B., TWOMEY, L. AND ALLISON, G.T. 1997. Altered abdominal muscle recruitment in patients with chronic back pain following a specific exercise intervention. *Journal orthopedic sports physical therapy*, 27(2): 114-124.

PANJABI, M.M. 1992. The stabilizing system of the spine. Part I. Function, dysfunction, adaptation and enhancement. *Journal of spinal disorders*, 5(4):383-9.

PANJABI, M.M. 1998. Cervical spine models for biomechanical research. *Spine*, Dec. 23:2684-700.

PANJABI, M.M, GOEL, V.K. & SUMMERS, D. 1982. Physiological strains in lumbar spinal ligaments, an in vitro biomechanical study. *Spine*. 7(3):192.

PANJABI, M.M., KRAG, M.H. & CHUNG, T.Q. 1984. Effects of disc injury on mechanical behaviour of the human spine. *Spine*, 9(7):707.

PANJABI, M.M. & WHITE, A.A. 2001. Biomechanics in the musculoskeletal system. Churchill Livingstone : Philadelphia. p 196.

PANJABI, M.M., WHITE, A.A. & JOHNSON, R.M. 1975. Cervical spine mechanisms as a function of transection of components. *J. Biomech.* 8:327.

PATWARDHAN, A.G., SONI, A.H., SULLIVAN, J.A., GUDAVALLI, M.R. AND SRINIVASAN, V. 1982. Kinematic analysis and simulation of vertebral motion under static load-part II: simulation study. *J biomech eng*, May. 104:112-8.

PAVLIDES, C., MIYASHITA, E. & ASANUMA, H. 1993. Projection from the sensory to the motor cortex is important in learning motor skills in the monkey. *J Neurophysiol* 70, pp. 733-741.

PEARSON, K. 2000. Motor systems. *Current Opinion in Neurobiology*, 10(5):649-654, Oct.

PECK, D., BUXTON, D.F. & NITZ, A. 1984. A comparison of spindle concentrations in large and small muscles acting in parallel combination. *J. Morphol.* 180, pp. 243-252.

PENNING, L. 1978. Normal movements of the cervical spine. *Am. J. Roentgenol* 130, pp. 317-326.

PETTY, N.J. & MOORE, A.P. 1998. Intertester reliability for selected clinical tests of the sacroiliac joint. *Physical Therapy*, 65(11):1671-1675.

PER-OLOF ÅSTRAND, M.D., KAARDE, R., DAHL, H.A. & STRØMME, S.B. 2003. Textbook of work physiology, physiological base of exercise. Fourth edition. Human Kinetics : Stanningly. P 649

POOL, J.J., HOVING, J.L., DE VET, H.C., VAN MAMEREN, H. & BOUTER, L.M. 2004. The interexaminer reproducibility of physical examination of the cervical spine. *Journal of Manipulative and Physiological Therapeutics*, 27(2):84-90, Feb.

POZZO, T., PAPAXANTHIS, C., STAPLEY, P. & BERTHOZ, A. 1998. The sensorimotor and cognitive integration of gravity. *Brain Research Reviews*, 28(1-2):92-101, Nov.

PRENTICE, W.E. 2004. Rehabilitation techniques for sports medicine and athletic training. Fourth edition. McGraw-Hill : New York. p 706.

RADIN, E.L. 1986. Role of muscles in protecting athletes from injury. *Acta medicine Scandinavia*, 711: 143-147.

REVEL, M., MINGUET, M., GERGORY, P., VAILLANT, J. & MANUEL, J.L. 1994. Changes in cervicocephalic kinaesthesia after a proprioceptive rehabilitation programme in patients with neck pain: A randomized controlled study. *Archives of Physical Medicine and Rehabilitation*, 75:895-899.

ROAF, R. 1960. A study of the mechanics of spinal injuries. *J. Bone Joint Surg.* 42B:810.

- ROBERTS, P.L. & MACLEOD, C. 1998. Automatic and strategic retrieval of structure knowledge following two modes of learning. *Quarterly Journal of Experimental Psychology* **52**, pp. 31-46.
- ROCABADO, M. 1999. Cervical Spine, v – 2: workbook. Santiago, Chile : Integramedica. 58 p.
- ROUX, C.E., GOEDEKE, R., VISSER, G.R., VAN ZYL, W.A. AND NOAKES, T.D. 1987. The epidemiology of schoolboy rugby injuries. *South african medical journal*, 71(5): 307-313.
- ROY, S.P. 1974. The nature and frequency of rugby injuries. A pilot study of 300 injuries at Stellenbosch. *South African medical journal*, 48: 2321-2327.
- SAGE, G.H. 1977. Introduction to motor behaviour: A neuropsychological approach. Second edition. Addison-Wesley Publishing Company : Massachusetts. p 610.
- SAKAI, K., HIKOSAKA, O., MIYAUCHI, S., TAKINO, R., SASAKI, Y. & PÚTZ, B. 1998. Transition of brain activation from frontal to parietal areas in visuo-motor sequence learning. *J Neurosci* **18**, pp. 1827-1840.
- SANDMARK, H. & NISELL, R. 1995. Validity of five common manual neck pain provoking tests. *Scandinavian journal of rehabilitation medicine*, Sep. 27:131-6.
- SAS Institute Inc., 1999. SAS Institute Inc., SAS OnlineDoc®, Version 8, Cary, NC.
- SAS Institute Inc. The SAS System for Windows Release 9.1 TS Level 1M0 Copyright© 2002-2003 by SAS Institute Inc., Cary, NC, USA.
- SAVAGE, A. 1995. Letters: Spinal cord injury in rugby union players. *British medical journal*, 311:511.

- SCHER, A.T. 1979. Unilateral locked facet in cervical spinal injuries. *AJR American journal of roentgenology*, 129:45-8.
- SCHER, A.T. 1980. Rugby injuries to the cervical spinal cord. *South African medical journal*, 58: 100.
- SCHER, A.T. 1981. The high rugby tackle – a continuing menace. *South African journal of sports medicine*, 11:3-5.
- SCHER, A.T. 1982. “Crashing” the rugby scrum – an avoidable cause of cervical spine injury: Case reports. *South African medical journal*, 61: 919-920.
- SCHER, A.T. 1990. Premature onset of degenerative disease of the cervical spine in rugby players. *South African medical journal*, 77:557-558.
- SCHER, A.T. 1991. Paralysis due to high tackle – a black spot in South African rugby. *South African Medical Journal*, 79:614-615.
- SCHER, A.T. 1998. Rugby injuries to the cervical spine and spinal cord: a 10-year review. *Clinical sports medicine*, 17:195-206.
- SCHER, M. 2004. The killing fields. FAIRLADY, 14 March, pp. 60-62.
- SCHILLING, B.K. & STONE, M.H. 2000. Stretching: Acute effects on strength and power performance. *Strength and Conditioning Journal*, 22(1):44.
- SCOTT, S.H. 2000. Population vectors and motor cortex: neural coding or epiphenomenon. *Nat Neurosci* 3, pp. 307-308.
- SECIN, F.P., POGGI, E.J., LUZURIAGA, F. AND LAFFAYE, H.A. 1999. Disabling injuries of the cervical spine in Argentine rugby over the last 20 years. *British journal of sports medicine*, 33:33-6.

- SEKIGUCHI, H., NAKAZAWA, K. & SUZUKI, S. 2003. Differences in recruitment properties of the corticospinal pathway between lengthening and shortening contractions in human soleus muscle. *Brain Research*, 977(2):169-179, Jul.
- SENG, K., PETER, V.L. & LAM, P. 2002. Neck muscle strength across the sagittal and coronal planes: an isometric study. *Clinical biomechanics* 17(7), pp. 545-547.
- SHEA, C.H., SHEBILSKE, W.L. & WORCHEL, S. 1993. Motor learning and control. Allyn and Bacon : Boston. p 351.
- SHEA, C.H. & WULF, G. 1999. Enhancing motor learning through external-focus instructions and feedback. *Human Movement Science*, 18(4):553-571, Aug.
- SHEN, L. & ALEXANDER, G.E. 1997. Neural correlates of a spatial sensory-to-motor transformation in the primary motor cortex. *J Neurophysiol* 77, pp. 1171-1194.
- SHERRINGTON, C. 1947. The integrative action of the nervous system. New Haven : Yale University Press.
- SHIRAZI-ADL, A., AHMED, A.M. AND SHRIVASTAVA, S.C. 1986. Mechanical response of a lumbar motion segment in axial torque alone and combined with compression. *Spine*, Nov. 11:914-27.
- SHIRAZI-ADL, S.A., SHRIVASTAVA, S.C. & AHMED, A.M. 1984. Stress analysis of the lumbar disc-body unit in compression: a three-dimensional nonlinear finite element study. *Spine*. 9(2):120.
- SILVER, J.R. 1975. Neck injuries: The constant threat to rugger players. *General Practitioner*, Sept.1:10.
- SILVER, J.R. 1984. Injuries of the spine sustained in rugby. *British medical journal*, 288: 37-43.

- SILVER, J.R. 1988. Rugby and neck injuries. *Injury*, 19(4):298.
- SILVER, J.R. 2002. The impact of the 21st century on rugby injuries. *Spinal cord*, Vol. 40 11:552-9.
- SILVERTHORN, D.U. 2001. Human Physiology, an integrated approach. Second edition. Prentice-Hall, Inc. : New Jersey. p 816.
- SIMON, B.R., WU, J.S., CARLTON, M.W., EVANS, J.H. AND KAZARIAN, L.E. 1985. Structural models for human spinal motion segments based on a poroelastic view of the intervertebral disk. *J biomech eng*, Nov. 107:327-35.
- SMETHURST, C.J. & CARSON, R.G. 2001. The acquisition of movement skills: Practice enhances the dynamic stability. *Human Movement Science*, 20(4-5):499-529, Nov.
- SNELL, R.S. 2001. Clinical neuroanatomy for medical students. Fifth edition. Lippincott Williams & Wilkens : London. p 545.
- STARKER, L. 2004. The computer revolution: Impact for musculoskeletal. (In 8th International Federation of Orthopaedic Manipulative Therapists' conference held in Cape Town, South Africa on 21 to 26 March 2004. p. 185-188)
- STERLING, M., JULL, G., VICENZINO, B., KENARDY, J. & DARNELL, R. 2003. Development of motor system dysfunction following whiplash injury. *Pain*, 102(1-2):65-73, May.
- STEYN, L. 2002. Lower limb biomechanical metrics of rehabilitated and non-rehabilitated South African schoolboy rugby players with previous knee pain or injury. Pretoria : UP. (Dissertation – MphysT [OMT]) 170 p.
- STONE, J.A. 2000. Prevention and rehabilitation: Proprioceptive neuromuscular facilitation. *Athletic Therapy Today*, 5(1):38-39.

STROEVE, S. 1998. Neuromuscular control model of the arm including feedback and feedforward components. *Acta Psychologica*, 100(1-2):117-131, Nov.

SUTCLIFFE, J. 2000. Physiotherapy briefing. Inside the human body. London : Bright Star Publishing plc. Part 74.

TAIMELA, S. KUJALA, U.N. AND OSTERMAN, K. 1990. Intrinsic risk factors and athletic injuries. *Sports medicine*, 9:205-215.

TAYLOR, T.K. AND COOLICAN, M.R. 1988. Rugby must be safer: preventive programmes and rule changes. *Medical journal of Australia*, 15;149(4):224.

TEO, E.C. & NG, H.W. 2001. Evaluation of the role of ligaments, facets and disc nucleus in lower cervical spine under compression and sagittal moments using finite element method. *Medical Engineering & Physics*, 23(3):155-164, Apr.

THACH, W.T. 1998. What is the role of the cerebellum in motor learning and cognition? *Trends in Cognitive Sciences*, 2(9):331-337, Sep.

THOMAS, J.R. & NELSON, J.K. 1985. Introduction to research in health, physical education, recreation and dance. Human Kinetics Publishers. Champaign : IL., p 414.

THOMPSON, R.E., PEARCY, M.J. & BARKER, T.M. 2004. The mechanical effects of intervertebral disc lesions. *Clinical Biomechanics* , pp. 1-13.

THOMPSON, R.F., THOMPSON, J.K., KIM, J.J., KRUPA, D.J. & SHINKMAN, P.G. 1998. The nature of reinforcement in cerebellar learning. *Neurobiol Learn Mem* 70, pp. 150-176.

TKACZUK, H. 1968. Tensile properties of human lumbar longitudinal ligaments. *Acta Orthop Scand*, 115 (suppl).

TOFLER, A. 1980. The third wave. Philadelphia : Collins. p 97

TORG, J.S. 1982. Athletic injuries to the head, neck, and face. Philadelphia : Lea & Febiger. p 127.

TORG, J.S. & PAVLOV, H. 1987. Cervical spine stenosis with cord neurapraxia and transient quadriplegia. *Clin Sports Med* 6/1, pp. 115-133.

TORG, J.S., VEGSO, J.J., O'NEILL, M.J. AND SENNET, B. 1990. The epidemiology, pathologic, biomechanical, and cinematographic analysis of football-induced cervical spine trauma. *American journal sports medicine*, 18:50-7.

TREW, M & EVERETT, T. 2001. Human Movement: an introductory text. 4th ed. Edinburgh : Churchill Livingstone. p 354.

UHLIG, Y., WEBER, B.R., GROB, D. AND MÜNTENAR, M. 1995. Fiber composition fiber transformations in neck muscles of patients with dysfunction of the cervical spine. *Journal orthopaedic research*, Mar. 13:240-9.

VAN DER WALT, E.J. 2004. Quoting sources, 3rd ed. Potchefstroom, Ferdinand Postma Library, PU for CHE. p 66.

VIRGIN, W. 1951. Experimental investigations into physical properties of intervertebral disc. *J. Bone Joint Surg.* 33B:607.

WALLER, A.E., FEEHAN, M., MARSHALL, S.W. AND CHALMERS, D.J. 1994. The New Zealand rugby injury and performance project: I. Design and methodology of a prospective follow-up study. *British journal of sports medicine*, 28(4): 223-228.

WATSON, A.W.S. 1981. Factors predisposing to sports injury in schoolboy rugby players. *Journal of Sports Medicine and Physical Fitness*, 21(4):417-422.

WEIGHTMAN, D. AND BROWNE, R.C. 1974. Injuries in association and rugby football. *British journal of sports medicine*, 2: 183-187.

WHITE, A.A. & PANJABI, M.M. 1990. Clinical Biomechanics of the spine. Second edition. Lippincott Williams & Wilkens : Philadelphia. p 722.

WHITING, W.C. & ZERNICKE, R.F. 1998. Biomechanics of Musculoskeletal Injury. United States of America : Human Kinetics. p 273.

WILK, K.E., ARRIGO, C.A. & ANDREWS, J.R. 1996. Closed and open chain exercises for the upper extremity. *Journal of Sport Rehabilitation*, 5:88-102.

WILKE, H.J., WOLF, S., CLAES, L.E., ARAND, M. & WIESEND, A. 1995. Stability increase of the lumbar spine with different muscle groups. A biomechanical in vitro study. *Spine* 20, pp. 192-198.

WINER, B.J. 1971. Statistical Principles in Experimental Design. 2nd ed. Tokyo: McGraw-Hill.

WOLPERT, D.M. & KAWATO, M. 1998. Multiple paired forward and inverse models for motor control. *Neural Networks*, 11(7-8):1317-1329, Oct.

WOLPERT, D.M., MIAL, R.C. & KAWATO, M. 1998. Internal models in the cerebellum. *Trends in Cognitive Sciences*, 2(9):338-347, Sep.

WORLD HEALTH ORGANIZATION. 2001. ICF Checklist 2.1a, clinician form for international classification of function, disability and health. [Online] Available <http://www.who/icf/checklist/icf-checklist.pdf> [Date of access January 2004].

WU, J.S. AND CHEN, J.H. 1996. Clarification of the mechanical behaviour of spinal motion segments through a three-dimensional poroelastic mixed finite element model. *Med eng phys*, Apr. 18:215-24.

WULF, G., HÖB, M. & PRINZ, W. 1998. Instructions for motor learning: Different effects of internal versus external-focus of attention. *Journal of motor behavior* 30, pp. 169-179.

- YANG, K. & KING, A. 1984. 1984 Volvo award in biomechanics: Mechanism of facet load transmission as a hypothesis for low-back pain. *Spine*. 9(6):557.
- YIN, J.C.P. & TULLY, T. 1996. CREB and the formation of long-term memory. *Curr Opin Neurobiol* 6, pp. 264-268.
- YOGANANDAN, N., KUMARESAN, S. & PINTAR, F. 2001. Biomechanics of the cervical spine Part 2. cervical spine soft tissue responses and biomechanical modelling. *Clinical Biomechanics*, 16(1):1:27.
- YOUNG, R.P. & MARTENIUK, R.G. 1998. Stereotypic muscle-torque patterns are systematically adopted during acquisition of a multi-articular kicking task. *Journal of Biomechanics*, 31(9):809-816, Sep.
- ZDEBLICK, T.A., ABITBOL, J.J., KUNZ, D.N., MCCABE, R.P. & GARFIN, S. 1993. Cervical stability after sequential capsule resection. *Spine* 18, pp. 2005-8.

APPENDIX A

SUBJECT INFORMED CONSENT FORM

TITLE OF STUDY:

Management of Cervical Biomechanical Dysfunction in Schoolboy Rugby Players using a Manual Physiotherapy Technique.

I, (capitals please) _____ (full names)
_____ (surname), I.D. _____ have read the
information below, had time to ask Ms Linda Steyn, MPhysT (OMT) questions,
received acceptable answers concerning any issues that I did not understand and I
willingly give my consent as a subject to participate in this study. In consideration of
my participation, I agree to indemnify Linda Steyn Physiotherapists Inc. and Burger
Radiologists Inc. from any claims or law suits.

This study is being conducted under the auspices of the Movement Science Education
Department, Faculty of Education Science, North West University as part fulfilment of
a doctorate (PhD) degree.

AIM OF THE STUDY

During biomechanical assessment of the necks of schoolboy rugby players the researcher
found biomechanical dysfunction in 80 % of all the players assessed. None of these
players had any neck pain or previous injury. This biomechanical dysfunction could
predispose a rugby player to neck injury or early degenerative changes of his neck. This
was indicated by various authors in the literature. The aim of this study will be to
compare the effectiveness of different approaches in the correction of the dysfunction and
then to maintain this correction with an appropriate neck exercise programme.

DESCRIPTION OF PROCEDURES

This study involves biomechanical assessment of the neck for possible biomechanical
dysfunction by means of a physiotherapeutic assessment technique as well as x-ray
analysis to confirm this. The study will include 4 groups of players and all subjects will
be x-rayed three times during a period of four months; prior to the start of the
intervention part of the study, after one month and finally after 4 months. X-ray views
will include lateral views of the neutral cervical spine as well as lateral views of the
cervical spine in flexion and extension. The emphasis will be on the analysis of the
intervertebral motion segment instead of pain provocative examination techniques. Data
from various intervention procedures to correct the biomechanical dysfunction will be
compared. This will provide physiotherapists in South Africa with the necessary
knowledge to assess and treat rugby players with biomechanical dysfunction of their
necks as well as establishing an effective home exercise programme.

You should understand that this study involves research and therefore volunteers will be evaluated to ensure that they comply with the necessary inclusion criteria of the study. To ensure that the results of the study are accurate it is important that no exceptions be made to these criteria for inclusion in the study. Each player who volunteers and complies with the inclusion criteria will be evaluated by the researcher in a room which ensures the necessary privacy. The player, his parent or guardian may request the presence of any other person of his or her choice to be present during the evaluation process. A pre-printed Evaluation Form will be completed by the researcher. The Evaluation Form is formatted in such a manner so as to ensure that results can be replicated by any other competent physiotherapist. The total process time of this initial physical evaluation will be approximately 20 minutes per player.

Following the initial assessment the players who comply with the inclusion criteria will be randomly allocated to one of the four groups. The players will undergo x-ray examination of their necks at a registered radiology practice located in Kempton Park. Transport to the radiology practice will be provided for the players. The players who have to perform the home exercise programme will exercise during normal rugby practise sessions and in the event of missing practice will have to perform the exercises at home. The group of players who will receive physiotherapy treatment will be treated at the school during a time that is convenient for them.

RISKS AND DISCOMFORT

As this study only involves a non-invasive physiotherapy assessment technique and a non-invasive x-ray technique no side effects should be experienced. If the player experience any discomfort he should inform the physiotherapist performing the evaluation immediately. Following the correction phase of the study the player will receive a neck strengthening exercise programme. None of the exercises should cause any pain, however discomfort such as experienced by fatigued muscles will be acceptable.

VOLUNTARY PARTICIPATION

Participation in this study is voluntary. No monetary compensation will be paid to any player subject. You must understand that the data obtained from your measurements may be used to develop a standardised neck rehabilitation programme for young rugby players. This programme could prove to decrease the morbidity of the cervical spine later on in the life of the schoolboy rugby player and possibly reduce the risk of a serious neck injury as a result of participating in rugby. It is for this reason that your participation is greatly appreciated. You are also free to withdraw your consent to participate in this programme at any time during the study period.

SUBJECT'S RESPONSIBILITIES

It will be expected of you to provide the researcher or research assistant with your full cooperation to ensure that the biomechanical measurements are carried out as accurately as possible and in the shortest time. If you are included in one of the exercise

groups it will be expected of you to comply with the exercise regime on your own if necessary.

CONFIDENTIALITY

All biomechanical measurements and other information of yourself will be kept confidential. The results obtained from the individual players who volunteer for the study may be published but you will remain anonymous. The raw data may be shared with the study supervisor, who is bound to confidentiality by ethical rules. You will be allowed to view the evaluation form after completion should you so request.

CONTACT PERSON

In the event that you would like to discuss any issue relating to the study please contact ms Linda Steyn of Linda Steyn Physiotherapists Inc, practise nr 7236948, Kempton Park, telephone nr (011) 394 8857 or 083 252 8107.

(subject signature) (date)

Home address: _____ (street)

(suburb)

(city)

Tel. numbers: Home () Cell _____

PARENT OR GUARDIAN

I, the undersigned parent or guardian have read all of the above, had time to ask questions, received acceptable answers concerning any issues that I did not understand and I willingly give my consent for my child to participate in this study. I understand that a copy of this signed form will be given to me at the earliest possible time if I so request. In consideration of my child's participation, I agree to indemnify Linda Steyn Physiotherapists Inc. and Burger Radiologists Inc. from any claims or law suits.

(parent/guardian signature) (date)

Name and surname in capitals _____
Home address: _____ (street)

(suburb)

(city)

Tel. numbers: Home (____) _____ Cell _____

Linda Steyn MPhysT (OMT)

(date)

(witness 1 for subject)

(witness 2 for parent/guardian)

APPENDIX B

Vertroulike vraelys

Die vraelys het nie 'n regte of verkeerde antwoord nie, dit toets slegs jou opinie. Antwoord asseblief eerlik en volgens jou eie kennis sodat 'n goeie program ontwikkel kan word vir die toekomstige veiligheid van alle rugby spelers. Die inligting van die antwoorde van hierdie vraelys sal vervat word in die doktrale proefskrif van Me Linda Steyn.

Datum _____
Naam en Van _____
ID Nommer _____
Ouderdom _____
Naam van skool _____
Speelposisie _____
Aantal jare van rugby deelname _____

1. Mediese geskiedenis:

Merk asseblief die toepaslike blokkie met 'n ✓

	Ja	Nee
1.1. Het jy enige siektetoestand wat moonlik jou nekbeweging kan beïnvloed?	☐	☐
1.2. Is jy gebore met enige abnormaliteite van jou nek?	☐	☐
1.3. Het jy 'n nekbesering opgedoen in die afgelope 12 maande wat jou vir langer as 'n week uit rugby uit gehou het en waarvoor jy mediese behandeling ontvang het?	☐	☐
1.4. Het jy enige mediese behandeling vir jou nek ontvang Gedurende die afgelope 3 maande?	☐	☐

2. Beserings geskiedenis:

Vir die doel van hierdie ondersoek word 'n rugby besering gedefinieer as enige rugby besering wat jou vir langer as 'n week uit rugby deelname gehou het en waarvoor jy mediese behandeling ontvang het.

Noem slegs die drie ernstigste beserings wat jy tydens rugby opgedoen het:

2.1. Beserings een:

2.1.1. Datum waarop die besering opgedoen is:

2.1.2. Liggaamsdeel beseer?

2.1.3. Hoe lank was jy afgeboek?

2.1.4. Tipe behandeling wat jy ontvang het?

Fisioterapie ☐ Doktersbesoek ☐

Medikasie ☐ Biokinetika ☐

2.1.5. Ondervind jy steeds probleme met die beserings?

Ja ☐ Nee ☐

2.2. Beserings twee:

2.2.1. Datum waarop die besering opgedoen is:

2.2.2. Liggaamsdeel beseer?

2.2.3. Hoe lank was jy afgeboek?

2.2.4. Tipe behandeling wat jy ontvang het?

Fisioterapie ☐ Doktersbesoek ☐

Medikasie ☐ Biokinetika ☐

2.2.5. Ondervind jy steeds probleme met die beserings?

Ja ☐ Nee ☐

2.3. Beserings drie:

2.3.1. Datum waarop die besering opgedoen is:

2.3.2. Liggaamsdeel beseer?

2.3.3. Hoe lank was jy afgeboek?

2.3.4. Tipe behandeling wat jy ontvang het?

Fisioterapie	☐	Doktersbesoek	☐
Medikasie	☐	Biokinetika	☐

2.3.5. Ondervind jy steeds probleme met die beserings?

Ja	☐	Nee	☐
----	--------------------------	-----	--------------------------

3. Nekbesering bewustheid:

Merk asseblief Ja of Nee vrae met 'n ✓

3.1. Is jy bewus van enige nekbeserings wat jou rugby kennisse opgedoen het oor die afgelope twee jaar? Ja ☐ Nee ☐

3.2. Is jy bewus van enige noodlottige nekbeserings in rugby gedurende die afgelope twee jaar? Ja ☐ Nee ☐

3.3. Het jou pa rugby gespeel? Ja ☐ Nee ☐

3.3.1. Indien jy ja geantwoord het, ondervind jou pa tans enige nek probleme? Ja ☐ Nee ☐

3.4. Het iemand al aan jou die gevare van rugby verduidelik (persoonlik of in span verband)? Ja ☐ Nee ☐

3.4.1. Indien jy ja geantwoord het, wanneer?

Laerskool	☐	Hoërskool	☐
Afgelope jaar	☐	Kan nie onthou nie	☐

3.4.2. Indien jyja geantwoord het, wie?

Ma	☐	Pa	☐
Afrigter	☐	Kurses	☐

3.5. Wanneer en hoe dink jy vind nekbeserings in rugby plaas?

Skrum	☐	Tackle	☐
Losgemaal	☐	Hoogvat	☐
Nie opwarm nie	☐	Vorige nekprobleme	☐

3.6. Het jy al ooit oorweeg om op te hou rugby speel weens die risiko van 'n nekbesering? Ja ☐ Nee ☐

3.7. Het jou ouers al ooit ontmoedig om rugby te speel?

Ja	☐	Nee	☐
----	--------------------------	-----	--------------------------

3.8. beïnvloed jou persepsie van risiko emigsins jou spel, met ander woorde, pas jy ooit jou spel aan omdat jy besef dat sekere spelpatrone tot 'n nekbesering kan lei? Ja ☐ Nee ☐

- 3.9. Is jy bang vir 'n nekbeseering? Ja ☐ Nee ☐
- 3.10. Dink jy dat jy enige nekprobleme sal hê in die toekoms?
Ja ☐ Nee ☐
- 3.11. Dink jy dat jy oor voldoende kennis beskik om jou nek teen beseerings te beskerm?
Ja ☐ Nee ☐
- 3.12. Beïnvloed groepsdruk jou deelname aan rugby?
Ja ☐ Nee ☐
- 3.13. Dink jy dat die tyd wat rugby-oefening van jou verg jou skoolwerk beïnvloed?
Ja ☐ Nee ☐

4. Nekspieroefeninge:

Merk asseblief Ja of Nee met 'n √

- 4.1. Dink jy jou nek is sterk genoeg vir rugby?
Ja ☐ Nee ☐
- 4.2. Dink jy dat jy voldoende tyd spandeer aan nekoefeninge?
Ja ☐ Nee ☐
- 4.3. Dink jy 'n sterk nek verminder die risiko van 'n nekbeseering?
Ja ☐ Nee ☐
- 4.4. Dink jy jou afrigter beskik oor genoeg kennis aangaande nekoefeninge?
Ja ☐ Nee ☐
- 4.5. Waar doen jy jou nekoefeninge?
Tuis ☐ Gedurende rugby oefening ☐
Gym ☐ Biokinetikus ☐
- 4.6. Hoeveel maal per week doen jy nekoefeninge?
Een maal ☐ Twee maal ☐
Drie maal ☐ Vier maal ☐
Vyf maal ☐ Meer as 5 maal ☐
- 4.7. Hoe lank spandeer jy aan nekoefening per oefensessie?
Een minuut ☐ Een tot 5 minute ☐
5 tot 10 minute ☐ 10 tot 15 minute ☐
Meer as 15 minute ☐
- 4.8. Wie het jou nekoefeninge vir jou geleer?
Afrigter ☐ Fisioterapeut ☐
Kurses ☐ Biokinetikus ☐
Ouers ☐ Ander ☐

4.9. Verander jou nekoefenprogram elke seisoen?

Ja ☐

Nee ☐

4.10. Wanneer tydens jou rugby loopbaan het jy begin met nekoefeninge?

Valkie rugby ☐

Laerskool ☐

Hoërskool ☐

Afgelope jaar ☐

4.11. Beskryf kortliks die nekoefeninge wat jy doen.

5. Afrigting aangaande fases van spel in rugby:

Merk asseblief jou antwoord met 'n ✓

5.1. Dink jy jy tackle goed? Ja ☐ Nee ☐

5.2. Dink jy daar word genoeg tyd spandeer aan tackle tegnieke tydens rugby oefening? Ja ☐ Nee ☐

5.3. Dink jy korrekte tackle tegnieke kan help om nekbeseerings te voorkom? Ja ☐ Nee ☐

5.4. Dink jy jou afrigter het genoeg kennis vir die afrigting van tackle tegnieke? Ja ☐ Nee ☐

5.5. Waar doen jy jou tackle oefeninge?
Tuis ☐ Tydens rugby oefening ☐
Gym ☐ Biokinetikus ☐

5.6. Hoeveel maal per week spandeer jy tyd aan tackle oefening?
Een maal ☐ Twee maal ☐
Drie maal ☐ Vier maal ☐
Vyf maal ☐ Meer as 5 maal ☐

5.7. Hoe lank spandeer jy aan tackle oefening op 'n slag?
Minder as 5 minute ☐ 5 tot 10 minute ☐
10 tot 15 minute ☐ meer as 15 minute ☐

5.8. Wie het die eerste maal vir jou geleer hoe om te tackle? Ja ☐ Nee ☐

5.9. Wanneer het jy die eerste maal leer tackle?
Valkie rugby ☐ Laerskool ☐
Hoërskool ☐ Afgelope jaar ☐

5.10. Verander die tackle tegnieke elke seisoen?

Ja ☐

Nee ☐

5.11. Beskryf kortliks hoe jy iemand tackle?

5.12. Dink jy voorspelers is meer geneig om nekbaserins op te doen?

Ja ☐

Nee ☐

5.13. Word daar meer nekoefeninge vir voorspelers gegee as vir die agterlyn?

Ja ☐

Nee ☐

5.15. Word voorspelers geleer hoe om hulle nekke te beskerm in die skrum?

Ja ☐

Nee ☐

5.16. Is jy geleer hoe om jou nek te beskerm in 'n losgemaal?

Ja ☐

Nee ☐

5.17. Word daar baie klem gelê op die gevare van hoogvat?

Ja ☐

Nee ☐

5.18. Word julle gestraf vir vuilspel tydens oefening of na 'n wedstryd?

Ja ☐

Nee ☐

6. Hoe gradeer jy jouself?

Merk asseblief jou keuse met 'n √

	Uitstekend	Bogemiddeld	Gemiddeld	Onderge- middeld	Swak
Liggaamskrag					
Koördinasie					
Balans					
Rugby 'skills'					
Vermoeë om nuwe tegnieke te leer					

APPENDIX C

Initial sifting form

School _____

NAME	TELEPHONE NUMBER	CERVICAL DYSFUNC	GROUP NR	AGE

APPENDIX D

SUBJECT ASSESSMENT FORM

The following information to be completed by the evaluating physiotherapist

Date _____

Name _____

I.D. number _____

Age _____

School _____

Playing position _____

Number of years participating in rugby _____

Medical history:

Please ✓

Systemic disease that may influence biomechanics ☐

Congenital neuromusculoskeletal dysfunction ☐

Any neck injury sustained during the previous 12 months ☐

Medical treatment during previous three months ☐

Subjective evaluation

Neurological signs and symptoms:

	Yes	No
Paraesthesia	☐	☐
Muscle weakness	☐	☐

Objective evaluation:

Body mass: _____ kg.

Cervical circumference _____ cm.

Cervical Spine:

	Stable	Unstable
Transverse ligament	☐	☐
Alar ligament left	☐	☐
Alar ligament right	☐	☐
	Decreased	Neutral
C ₀ /C ₂ space	☐	☐

C₁:

- i. Held in left rotation ☐
- ii. Held in right rotation ☐
- iii. Neutral ☐

C₂:

- i. Side bending restriction left ☐
- ii. Side bending restriction right ☐
- iii. Neutral ☐

C₂/C₃:

- i. Dysfunction on the left with left rotation left side bending restriction ☐
- ii. Dysfunction on the left with left rotation right side bending restriction ☐
- iii. Dysfunction on the right with right rotation right side bending restriction ☐

- iv. Dysfunction on the right with right rotation left side bending restriction ☐
- v. Bilateral Dysfunction ☐
- vi. Neutral ☐

C₃/C₄:

- i. Dysfunction on the left with left rotation left side bending restriction ☐
- ii. Dysfunction on the left with left rotation right side bending restriction ☐
- iii. Dysfunction on the right with right rotation right side bending restriction ☐
- iv. Dysfunction on the right with right rotation left side bending restriction ☐
- v. Bilateral Dysfunction ☐
- vi. Neutral ☐

C₄/C₅:

- i. Dysfunction on the left with left rotation left side bending restriction ☐
- ii. Dysfunction on the left with left rotation right side bending restriction ☐
- iii. Dysfunction on the right with right rotation right side bending restriction ☐
- iv. Dysfunction on the right with right rotation left side bending restriction ☐
- v. Bilateral Dysfunction ☐
- vi. Neutral ☐

C₅/C₆:

- i. Dysfunction on the left with left rotation left side bending restriction ☐
- ii. Dysfunction on the left with left rotation right side bending restriction ☐
- iii. Dysfunction on the right with right rotation right side bending restriction ☐
- iv. Dysfunction on the right with right rotation left side bending restriction ☐
- v. Bilateral Dysfunction ☐
- vi. Neutral ☐

C₆/C₇:

- i. Dysfunction on the left with left rotation left side bending restriction ☐
- ii. Dysfunction on the left with left rotation right side bending restriction ☐
- iii. Dysfunction on the right with right rotation right side bending restriction ☐
- iv. Dysfunction on the right with right rotation left side bending restriction ☐
- v. Bilateral Dysfunction ☐

vi. Neutral

☐

	Left		Right	
	Left rotation, left side bending	Left rotation, right side bending	Right rotation, right side bending	Right rotation, left side bending
C ₂ /C ₃				
C ₃ /C ₄				
C ₄ /C ₅				
C ₅ /C ₆				
C ₆ /C ₇				

Mark the restriction

Neurodynamic tests:

	Positive	Negative
PNB	☐	☐
ULTT I left	☐	☐
ULTT I right	☐	☐

	Yes	no
X-ray assessment	☐	☐

APPENDIX E

SUBJECT TREATMENT SHEET

NAME: _____

GROUP: _____

DATE OF ASSESSMENT _____

TREATMENTS:

[illegible]

APPENDIX F

FINALE VRAELYS:

Antwoord asseblief eerlik en volgens jou eie kennis sodat 'n goeie program ontwikkel kan word vir die toekomstige veiligheid van alle rugby spelers. Die inligting van die antwoorde van hierdie vraelys sal vervat word in die doktorale proefskrif van Me Linda Steyn.

Datum _____

Naam en Van _____

Naam van skool _____

Merk asseblief jou keuse met ✓

	Ja	Nee
1. Het jy jou oefeninge gereeld gedoen?	☐	☐
2. Kon jy al die oefeninge doen?	☐	☐
4. Indien jy nee geantwoord het beskryf kortliks watter oefening jy nie kon doen nie.		

5. Het jy enige nekpyn ervaar gedurende die oefeninge?	☐	☐
6. Het jy enige nekpyn ervaar na afloop van die oefeninge?	☐	☐
7. Dink jy die oefeninge kan help om nekbaserings in rugby te verminder?	☐	☐
8. Dink jy die oefeninge kan help om jou kanse op nekprobleme in die toekoms te verminder?	☐	☐
9. Enige kommentaar of voorstelle?		

