Upper body anthropometrical differences amongst participants of asymmetrical (fast bowlers in cricket) and symmetrical (crawl stroke swimmers) sport and sedentary individuals in South Africa

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FOREWORD

The following quote summarises the sentiment I have on the topic I chose to keep myself "asymmetrically" pre-occupied for the last five years:

"That some of these relations exist is no less amazing than that someone was inspired to study them." Anon.

The completion of this study was made possible by the contribution of numerous individuals. I would like to express my sincere appreciation to the following:

> My Heavenly Father, who formed me with precious love according to the divine purpose He has for my life, and for the grace and mercy He has poured out upon me. I want to walk in Your complete will for my life! Please guide me in that.

> Jesus Christ, my saviour and Lord, with whom I have a personal relationship, for what He has done in and through my life. My hearts desire is to become more and more like You Lord!

> The Holy Spirit, who is my Counselor, Helper, Advocate, Intercessor, Strengthener and Standby. I thank You and rely on You for the different roles You play in my daily life.

- To my family:
  - My parents, the completion of this study would not have been possible without you! Thanks for being a major part of the first twenty-seven years or so of my life! Your love, understanding and encouragement are greatly appreciated. Thank you also for the valuable lessons I learned from you, which assisted me in becoming what I am today. I hope to be a role model for your grandchildren one day, similar to what you are to me. You guys really mean the world to me!
  - My sister, Tania whom I love very much. You are a class act! I am proud to have you as my sister. Your high moral standards and sparkling personality can be compared to a lighthouse on top of a high mountain... something everyone can see, and which they can use as a beacon for their ways. I miss the quality times we spent when you were studying in Potchefstroom. Hopefully that'll change soon...
  - My "little" brother, Ivan. You're an awesome brother, friend and you're my hero! You better watch out though, because your big brother is watching!

- Prof. Hans De Ridder as supervisor, colleague and friend. Thank you for the expertise and effort you have put into this study, but even more so for all the support you have given me during the last couple of years. You have imparted on me the importance of a balanced life, in the way your family takes first priority in your life.
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Heinrich Grobbelaar

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DECLARATION

The co-authors of the two articles which form part of this dissertation, Prof. J. Hans De Ridder (supervisor) and Mr. Ben Coetzee (co-supervisor), hereby give permission to the candidate, Mr. Heinrich W. Grobbelaar to include the two articles as part of a Masters dissertation. The contribution (advisory and supportive) of these two co-authors was kept within reasonable limits, thereby enabling the candidate to submit this dissertation for examination purposes. This dissertation, therefore, serves as partial fulfilment of the requirements for the M.Sc. degree in Sport Science within the School of Biokinetics, Recreation and Sport Science in the Faculty of Health Sciences at the Potchefstroom University for Christian Higher Education.

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Supervisor and co-author

Mr. Ben Coetzee
Co-supervisor and co-author

SUMMARY

The prevalence of morphological asymmetry amongst sport participants and sedentary individuals has been well documented. The importance of studies in this field is accentuated by the fact that morphological asymmetry has a negative effect on the health and performance of elite athletes. The purpose of this study was, therefore, firstly to determine whether significant differences for thirty five anthropometrical measurements exist between the dominant and non-dominant sides of male (n = 16) and female (n = 11) crawl stroke swimmers. Dependent t-tests were used for this purpose. All of the measurements were taken twice on both the dominant and non-dominant sides of the body, according to the methods described by Norton et al. (1996). Amongst the male swimmers, the (relaxed-, tensed- and corrected-) upper arm girths, wrist girth, thigh girth and lower leg length showed statistically significant ($p < 0.05$) differences. Amongst the female swimmers statistically significant ($p < 0.05$) differences were found for the thigh girth, upper leg length and foot length. The second purpose was to compare the indices of morphological asymmetry of twenty upper body anthropometrical variables of the male swimmers to that of male fast bowlers (n = 27) and aged-matched sedentary males (n = 27). This comparison was done using an ANOVA with Tukey post hoc tests. The indices of morphological asymmetry were determined with Wolański's Relative Indices of Asymmetry (RIA). The RIA for the twenty upper body measurements for the three groups in this comparison are also reported. Statistically significant ($p < 0.05$) differences were found for the (relaxed, tensed and corrected) upper arm girths and half-chest girth when the fast bowlers were compared to the male swimmers as well as for the comparison between the fast bowlers and the sedentary individuals. A statistically significant ($p < 0.05$) difference was also found for the hand length between the fast bowlers and the sedentary individuals. To conclude, all four of the measured groups showed indices of morphological asymmetry for certain anthropometrical variables, with the fast bowlers showing the highest indices and the swimmers showing the lowest indices of morphological asymmetry. These results support the notion that swimming may have preventive and therapeutic value for athletes who show a high degree of morphological asymmetry due to participation in unilateral sport types. Further research is, however, required.

Key words: Asymmetry, fast bowlers, cricket, crawl stroke, swimmers, sedentary individuals, South Africa.

OPSOMMING

Die voorkoms van morfologiese asimmetrie onder sportdeelnemers en sedentêre persone is goed gedokumenteer. Die belangrikheid van studies oor hierdie onderwerp word beklemtoon deur die feit dat morfologiese asimmetrie 'n negatiewe effek op die gesondheid en prestasies van elite sportlui het. Die doel van die studie was gevolglik eerstens om te bepaal of betekenisvolle verskille tussen die dominante- en nie-dominante kante van manlike (n = 16) en vroulike (n = 11) kruipslagswemmers voorkom vir vyf-en-dertig antropometriese veranderlikes. Alle metings is twee maal aan beide die dominante- en nie-dominante kante geneem, volgens die metodes van Norton et al. (1996). Statisties betekenisvolle (p < 0,05) verskille is by die mans gevind vir die (ontspanne-, gespanne- en gekorrigeerde-) boarmomtrekke, gewrigomtrek, dyomtrek en onderbeenlengte. Statisties betekenisvolle (p < 0,05) verskille is by die dames gevind vir die dyomtrek, bobeenlengte en voetlengte. Die tweede doel was om die indeks van asimmetrie vir twintig bolyf antropometriese veranderlikes van die manlike swemmers te vergelyk met dié van manlike snelboulers (n = 27) en sedentêre mans (n = 27) van dieselfde ouderdom. Die indeks van asimmetrie is met behulp van Wolański se Relatiewe Indeks vir Asimmetrie (RIA) bepaal. Die RIA vir die twintig bolyf antropometriese veranderlikes vir die drie groepe wanneer vergelykings getref word, word geraporteer. 'n Statisties betekenisvolle (p < 0,05) verskille is gevind vir die (ontspanne-, gespanne- en gekorrigeerde-) boarmomtrek asook die halwe borsomtrek wanneer die manklike snelboulers onderskeidelik met die swemmers en die sedentêre persone vergelyk word. 'n Statisties betekenisvolle (p < 0,05) verskil is ook gevind vir die handlengte tussen die snelboulers en die sedentêre persone. Om saam te vat, toon al vier die getoetsde groepe 'n mate van asimmetrie vir sekere antropometriese veranderlikes, met die snelboulers wat die hoogste- en die swemmers wat die laagste mate van morfologiese asimmetrie toon. Hierdie resultate ondersteun die mening dat swem van voorkomende en terapeutiese waarde mag wees vir sportlui met 'n hoë mate van morfologiese asimmetrie vanwee hul deelname aan asimmetriese sportsoorte. Verdere navorsing word egter benodig.

Sleutel terme: Asimmetrie, snelboulers, krieket, kruipslag, swemmers, sedentêre persone, Suid Afrika.

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ARTICLE 1: ASYMMETRY IN THE UPPER BODY OF HIGH SCHOOL FAST BOWLERS IN CRICKET IN SOUTH AFRICA

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LIST OF ABBREVIATIONS

n	Number of subjects in each subgroup
RIA	Relative Indices of Asymmetry
UCBSA	United Cricket Board of South Africa
PU for CHE	Potchefstroom University for Christian Higher Education
AJPHERD	African Journal for Physical, Health Education, Recreation and Dance
OED	Oxford English Dictionary
D	Dominant
ND	Non-dominant
$\overline{X}$	Average
SD	Standard Deviations
mm	millimetres
cm	centimetres
ml	millilitres
NS	Not significant
SPAPQ	Sport Participation Activity Profile Questionnaire
ANOVA	One-way analysis of variance
g	gram
FB	Fast Bowlers
SW	Crawl Stroke Swimmers
SM	Sedentary Males

1 Problem statement and purposes of the study

1.1 PROBLEM STATEMENT

The occurrence of morphological asymmetry in different types of sport have been well documented (Buskirk *et al.*, 1955; Chinn *et al.*, 1974; Czabanski, 1974; Copley, 1980; Montoye *et al.*, 1980; Zaharieva, 1981; Powers & Walker, 1982; Pirnay *et al.*, 1987; Wyss *et al.*, 1989; Nyström *et al.*, 1990; Swärd *et al.*, 1990; Stretch, 1991; Groppel & Roetert, 1992; Coetzee, 1994; Margonato *et al.*, 1994; Green *et al.*, 1996; Kippers *et al.*, 1998; Krawczyk *et al.*, 1998; Carson, 1999; Engstrom *et al.*, 1999; Jansen van Rensburg, 2000). Further evidence suggests that such morphological asymmetries are also prevalent amongst sedentary individuals (Laubach & McConville, 1967; Womersley & Durnin, 1973; Ruff & Jones, 1981; Martorell *et al.*, 1988; Dangerfield, 1994; Margonato *et al.*, 1994). It is the interest of this study to compare the incidence and degree of morphological asymmetry amongst participants in specific asymmetrical and symmetrical sports (cricket and swimming respectively) and sedentary individuals.

Miller and Brackman Keane (1987:120) defined asymmetry as "a lack or absence of symmetry" and "a dissimilarity in the corresponding parts or organs on opposite sides of the body that are normally alike". According to Gomez (1994:47), morphological asymmetries can be accredited to physical activity, environmental factors and inherent factors such as laterality, handedness and side dominance. Zaharieva (1981:148) further stressed that morphological limb asymmetry is highly dependent on the kind of sport practised. In this regard, Pirnay *et al.* (1987:331) stated that participants of asymmetrical sport develop morphological asymmetry due to the asymmetrical physical and neurological demands that are placed on the locomotor apparatus of the dominant limb, compared to the non-dominant limb. Normal daily activities (in which the tendency is to make greater functional use of the dominant limb, compared to the non-dominant limb) were also indicated as a contributing factor to asymmetrical development (Dangerfield, 1994:20; Margonato *et al.*, 1994:569). It is the functional, morphologically observable and measurable asymmetry resulting from participation in certain asymmetrical and symmetrical sports that are of interest in this study.

Most of the available research on morphological asymmetry in sport focuses on the occurrence thereof amongst tennis players (Buskirk *et al.*, 1955; Chinn *et al.*, 1974; Copley, 1980; Montoye *et al.*, 1980; Zaharieva, 1981; Powers & Walker, 1982; Pirnay *et al.*, 1987; Wyss *et al.*, 1989; Swärd *et al.*, 1990; Groppel & Roetert, 1992; Green *et al.*, 1996; Krawczyk *et al.*, 1998; Jansen van Rensburg, 2000). Significant differences between the dominant and non-dominant sides for the forearm girth, wrist girth and wrist width (Green *et al.*, 1996:945), humerus length (Wyss *et al.*, 1989), humerus width, and ulna and radius width (Montoye *at al.*, 1980) are just some of the reported findings.

Research also indicates morphological asymmetries amongst épée fencers (Azemar, as quoted by Pirnay *et al.*, 1987; Nyström *et al.*, 1990; Margonato *et al.*, 1994). In this regard, Margonato *et al.* (1994:569), for example, found a significant difference ($p < 0.001$) in the dominant forearm cross sectional area of épée fencers when the dominant and non-dominant sides were compared.

Indices of morphological asymmetries have also been reported amongst fast bowlers in cricket (Stretch, 1991; Bloomfield *et al.*, 1994; Kippers *et al.*, 1998). These researchers all demonstrated asymmetrical development of the body structure of fast bowlers. In this regard, Bloomfield *et al.* (1994:102) illustrated the over-development of the dominant side of the upper body in a high level fast bowler by means of a photograph. Similar results concerning lower body morphological asymmetry were reported by Stretch (1991:62-63), who found that a number of bowlers in his study exhibited larger calf girths of the leg opposite to the bowling arm, when compared to the leg on the dominant side. Kippers *et al.* (1998:106) also found that small indices of morphological asymmetry exist when the dominant and non-dominant limb measurements of these players are compared. It can, therefore be concluded that morphological asymmetry does exist amongst participants of asymmetrical sport, such as tennis players, épée fencers and fast bowlers in cricket.

The prevalence of morphological asymmetries amongst swimmers was also indicated (Czabanski, 1974; Zaharieva, 1981; Perrin, 1993; Coetzee, 1994). In a comparative study on the participants of 14 different sports, Zaharieva (1981:143) demonstrated that swimmers had the lowest percentage for morphological asymmetry of the upper arm girth. Of these swimmers, 49.9% did, however, show a difference of greater than 0.3 cm between the dominant and non-dominant side measurements for this specific girth. Perrin (1993:67) indicated that few morphological differences between the dominant and non-dominant sides were observed in athletes who participate in sport (such as swimming) where bilateral, symmetrical development of the upper body and extremities occur. These findings were substantiated by Czabanski (1974:211) and Coetzee (1994:16), in studies on the anthropometrical profiles of junior swimmers.

Although it seems that sports participants (especially those involved in asymmetrical sport types) are more prone to asymmetrical development, research has shown that morphological asymmetry could also be prevalent amongst normal sedentary individuals (Laubach & McConville, 1967; Womersley & Durnin, 1973; Dangerfield, 1994). Dangerfield (1994:10-11) found that the dominant limbs of such individuals may be larger (1-3%) and heavier (2-4%) than the non-dominant limbs. This researcher also indicated a greater degree of asymmetry in the upper limbs than in the lower limbs. These findings are further accentuated by Laubach and McConville (1967:368) who found that the upper arm girth (both relaxed and tensed), forearm girth, wrist girths and hand breadth of the dominant side were statistically significantly larger than that of the non-dominant side. However, no statistically significant differences were observed in the comparison of dominant and non-dominant skinfold measurements of sedentary individuals (Womersley & Durnin, 1973:289). The above mentioned literature results seem to indicate that handedness and other inherent factors plays a significant role in the onset and development of morphological asymmetry amongst sedentary individuals.

The occurrence of morphological asymmetry amongst sedentary individuals and especially sport participants makes it an important research subject. This aspect becomes even more important when the negative effects thereof are evaluated. In this regard, Starosta (1989) stated that morphological asymmetry could lead to the reduction of an athletes' range of movement in certain joints. The internal rotation of the shoulder on the dominant side of tennis players was, for example, significantly less than on the non-dominant side (Chandler *et al.*, 1990:135). Similarly, Chinn *et al.* (1974:476) found a significant reduction in the radial-ulnar pronation and supination in the dominant forearms of tennis players.

Starosta (1989) also stressed that such athlete's health could be influenced negatively by the degree of morphological asymmetry in certain body segments. Swärd (1992:362) subsequently reported a scoliosis frequency of more than 80% amongst participants of sport (such as javelin and tennis) in which movements occur where an asymmetrical load is placed on the trunk and shoulders. This is in line with the portrayed over-development and accompanying scoliosis of a high level fast bowler by Bloomfield *et al.* (1994:102). It is in the light of these and other research findings that the United Cricket Board of South Africa (UCBSA) Research Committee (2000:1) that addresses back injuries decided to focus on screening protocols for the identification and evaluation of morphological asymmetry and scoliosis amongst young developing fast bowlers. They also claim that morphological asymmetries may be a possible contributing factor in the complex aetiology of back injuries amongst fast bowlers, although they stressed that further research is needed to substantiate this viewpoint.

It is against this background that the importance of research on the possible occurrence of morphological asymmetry amongst fast bowlers, swimmers and sedentary individuals are brought to light. The research questions that arise are firstly whether significant differences between the dominant and non-dominant sides exist (for selected anthropometrical measurements) amongst fast bowlers, crawl stroke swimmers and sedentary individuals. Secondly, how do these three groups differ with regard to the indices of morphological asymmetry in their upper bodies.

Answers to these research questions could be of great value to the Sport Scientist, Biokineticist, Physiotherapist and the other role-players within the sporting fraternity. It would focus these professionals' attention on the importance of specific preventive and therapeutical exercises for morphological asymmetry amongst sport participants. This study also aims to draw exercise professionals' attention to swimming as a possible preventive exercise for the onset of such morphological asymmetries and for the improvement of symmetry amongst participants of asymmetrical sport, thereby positively contributing to the health and performance of these athletes.

1.2 PURPOSES

The purposes of this study are:

1.2.1 Firstly, to determine whether fast bowlers, crawl stroke swimmers and aged-matched sedentary individuals show significant differences between the dominant and non-dominant sides for selected anthropometrical measurements

1.2.2 Secondly, to compare the fast bowlers, crawl stroke swimmers and aged-matched sedentary individuals with regard to the indices of morphological asymmetry in the upper body.

1.3 HYPOTHESES

This study is based on the following hypotheses:

1.3.1 Fast bowlers will show significant differences between the dominant and non-dominant side measurements for selected anthropometrical variables

1.3.2 Crawl stroke swimmers and sedentary individuals will show small, but significant differences between the dominant and non-dominant side measurements for selected anthropometrical variables

1.3.3 Fast bowlers will show significantly greater indices of morphological asymmetry for selected upper body anthropometrical variables than the crawl stroke swimmers and sedentary individuals.

1.4 STRUCTURE OF THE DISSERTATION

From the problem statement it is clear that morphological asymmetry is present amongst participants of both asymmetrical and symmetrical sport as well as normal sedentary individuals. This dissertation, therefore, discusses the prevalence of morphological asymmetries amongst these different groups and the causes, effects and implications thereof for the exercise professionals. Recommendations for the improvement of these athletes' health (by preventing and remedying asymmetrical differences) and performances will also be brought to light.

The dissertation is submitted in article format as approved by the Senate of the Potchefstroom University for Christian Higher Education (PU for CHE) and is structured as follows:

- Chapter 1 consists of the problem statement, purposes of the study and the hypotheses thereof. A source list is provided at the end of the chapter according to the prescriptions of the PU for CHE

- Chapter 2 is a literature review on the prevalence of morphological asymmetries amongst sport participants and sedentary individuals. This literature overview will be used to construct the problem statement for each of the two articles (Chapters 3 and 4). The two articles will further incorporate the research methods and results of this study. A source list is presented at the end of this chapter according to the prescriptions of the PU for CHE

- Chapter 3 is a research article on the comparison between the upper body morphological asymmetry between fast bowlers in cricket and aged-matched sedentary individuals. This article has been published in the *"African Journal for Physical, Health Education, Recreation and Dance, 2001: 7(1):61-76. (Asymmetry in the upper body of high school fast bowlers in cricket in South Africa. Grobbelaar, H.W. and De Ridder, J.H.)."* The article is hereby included with the consent of the journal's editor, according to the specific prescriptions of the journal. The guidelines for contributors are included as Appendix A

- Chapter 4 is a research article that deals with the incidence of morphological asymmetry amongst top South African crawl stroke swimmers. The results of the swimmers indices of morphological asymmetry are also compared to those of cricket players (fast bowlers) and sedentary individuals. This article will be presented for publication in the *"Journal of Sports Sciences".* The article is hereby included according to the specific prescriptions of the journal. The Instructions for authors are included as Appendix B

- Chapter 5 consists of a short summary, followed by conclusions drawn from this study, the recommendations and implications for further studies on this topic. A source list is presented at the end of the chapter according to the prescriptions of the PU for CHE.

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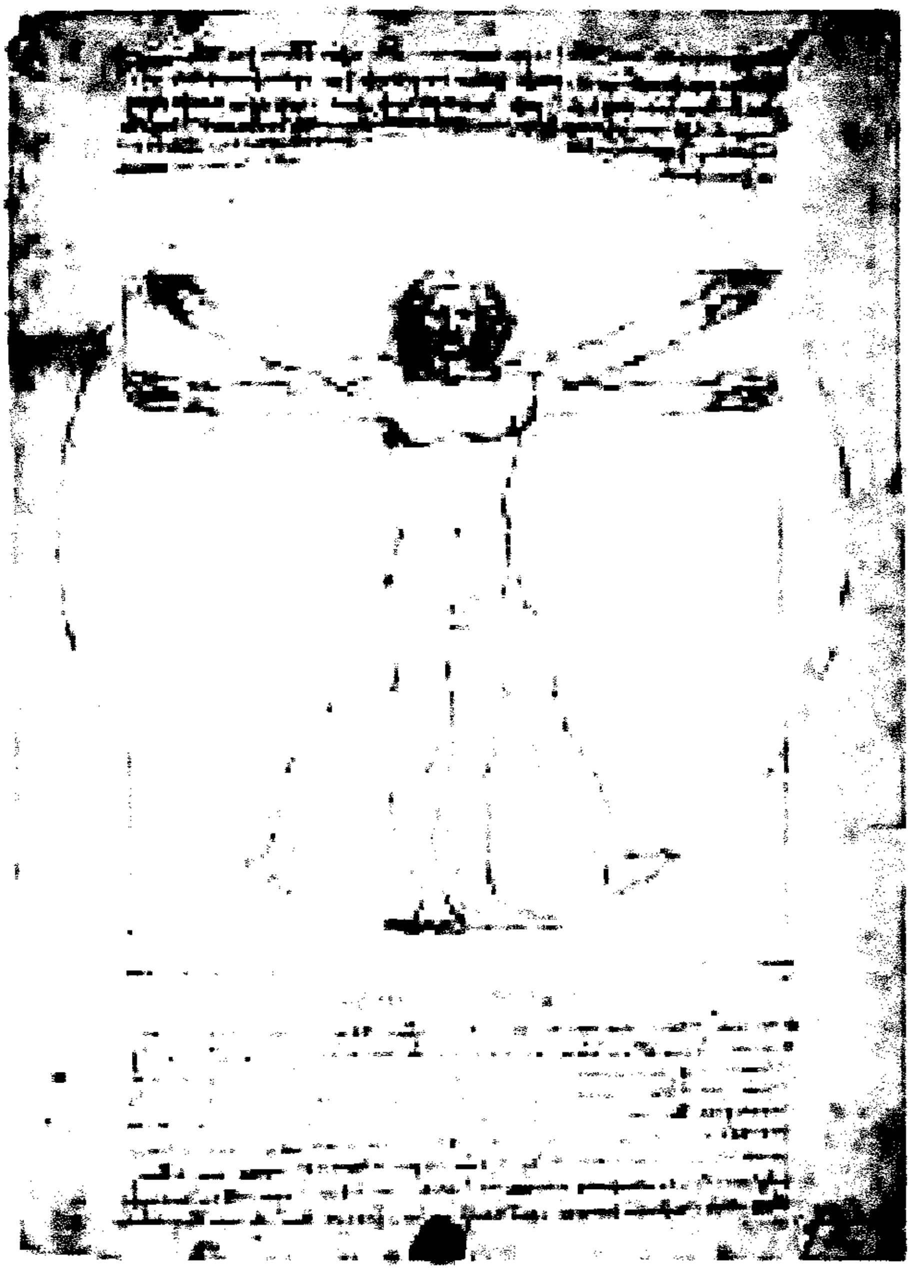
2 The morphological asymmetry amongst sport participants and sedentary individuals



The Vitruvian man painting by Leonardo da Vinci.

2.1 INTRODUCTION

At the elite sport level a strong relationship exists between human morphology and functioning (Grimston & Hay, 1986:60; Stretch, 1991:57; De Ridder *et al.*, 2000:39). The study of morphology (the science of structure and form without regard to function (Carter, 1985:106)) and the effect thereof on sporting performance has as a result become an important research topic. To further substantiate the importance of this research topic, Becker (1986:155) concluded that the musculature development of an athlete has a strong influence on performance and is functionally specific to the sport activity of participation. The musculature development has an influence on performance due to the specific demands of the type of sport or item as well as the playing position that the athlete holds. In this regard, Stretch (1991:57) stated that morphology in itself is not the only criterion for optimum performance in sport, but added that any deviations from the optimum standards could be a handicap in performing well. Carter (1985:115) contributed to this debate by stressing that athletes who have, or acquire the optimal physique for an event are more likely to succeed than those who lack these characteristics. Groppel and Roetert (1992:262) are further of the opinion that specific programmes must be developed to improve any deficient physical and/or physiological attributes, so as to further improve sporting performance.

One aspect of the morphology of both sport participants and the normal sedentary population that has not been thoroughly researched, is that of asymmetry. Literature on morphological asymmetry does exist, but according to Starosta (1989), many questions still need to be answered to gain more knowledge of this subject. The relationship that exists between morphological limb asymmetry of athletes and their physical fitness, as well as their performance, focuses even more attention to this topic (Zaharieva, 1981:142). Over and above these reasons, the negative effects of morphological asymmetry cast an even bigger light on the importance of this research topic (Starosta, 1989).

Chinn *et al.* (1974:482) indicated the need for more research on morphological asymmetry within the sporting context, specifically to analyse unilateral sport activities and the effect thereof on the morphological adaptations and performances of participants of such sport. Studies on morphological asymmetry were seldom conducted with the emphasis of indicating these asymmetries amongst sport participants. It mostly formed part of broader studies on the morphological profiles of sport participants, and mainly focused on the effects of unilateral activities on the physical and/or physiological attributes of the dominant limbs, compared to the non-dominant limbs. Such studies mostly involved tennis players as they almost exclusively use a single upper extremity. According to Pirnay *et al.* (1987:331) and Priest (1988:387), tennis (and therefore all sport of which the movements can be classified as unilateral) with its unilateral solicitations would allow for a more precise examination of specific localised development. As a result of these statements and earlier research findings concerning unilateral sports, numerous studies involving tennis players were conducted, which revealed that morphological and/or physiological adaptations do occur due to chronic unilateral exercises (Buskirk *et al.*, 1955; Copley, 1980; Montoye *et al.*, 1980; Zaharieva, 1981; Powers & Walker, 1982; Pirnay *et al.*, 1987; Wyss *et al.*, 1989; Swärd *et al.*, 1990; Groppel & Roetert, 1992; Green *et al.*, 1996; Krawczyk *et al.*, 1998; Jansen van Rensburg, 2000). In the above-mentioned studies, these morphological adaptations give rise to statistically significant indices of morphological asymmetry amongst tennis players.

Similar results were also observed amongst épée fencers (Azemar, as quoted by Pirnay *et al.*, 1987; Nyström *et al.*, 1990; Margonato *et al.*, 1994) and fast bowlers (Stretch, 1991; Bloomfield *et al.* 1994; Engstrom *et al.*, 1997; Kippers *et al.*, 1998). In contrast to these findings, a few studies (Czabanski, 1974; Zaharieva, 1981; Perrin, 1993; Coetzee, 1994) also found that few morphological differences exist between the dominant and non-dominant sides of swimmers (participants of a bilateral sport). This leads the author of this study to argue that swimming can possibly be used as a preventive exercise for the onset of morphological asymmetries and for the improvement of symmetry for participants of asymmetrical sport.

Studies on the indices of morphological asymmetry of the sedentary population have also been conducted (Laubach & McConville, 1967; Womersley & Durnin, 1973; Ruff & Jones, 1981; Martorell *et al.*, 1988; Dangerfield, 1994; Margonato *et al.*, 1994). The sedentary population does show asymmetrical development for certain morphological variables, which can be attributed mainly to side dominance and normal daily activities. This group can, therefore be used as a control group to evaluate the nature, causes and degree of asymmetry amongst athletes. It is in the light of the above research findings that this study on the prevalence of morphological asymmetry amongst fast bowlers, crawl stroke swimmers and sedentary individuals was conducted.

In order to demonstrate any relationships between morphological asymmetry and sport participation, the measurement procedures thereof need to be accurate and valid. The following sections will, therefore, firstly deal with the definitions of asymmetry and other related terminology, as well as the criteria and methods for calculating asymmetry.

2.2 DEFINING ASYMMETRY AND OTHER RELATED TERMINOLOGY

Miller and Brackman Keane (1987:120) defined asymmetry as "a lack or absence of symmetry", and "a dissimilarity in the corresponding parts or organs on opposite sides of the body that are normally alike". According to the Oxford English Dictionary (OED, 1987), asymmetrical refers to being "not symmetrical, with the parts not arranged correspondingly". Another term used in the same context as asymmetry, is dysplasia (Battinelli, 1976:465), which can be defined in terms of the degree to which one part of the body is disproportionate to another. "The quality of having distinct sides", "sidedness", or "excessive development on one side" is referred to as laterality (OED, 1987) and is also regularly cited in the literature.

Movements can further be divided into unilateral and bilateral movements according to the "sidedness" of movements. Unilateral movements refers to "one-sided" movements, movements that are "directed towards one side" or movements that "affect or lead to the development of one side of the body" (OED, 1987). In contrast to unilateral movements, bilateral movements are movements that "pertain to or affect two sides" and lead to changes "on opposite sides of an axis" (OED, 1987). In the case of bilateral movements, both sides of the body are, therefore "equally" involved in the movements. The word "equally" is deliberately placed in inverted commas, as there is evidence that suggests that even during the execution of bilateral movements, one side of the athlete's body (dominant side) is more involved in the action than the other side (Becker, 1986:153; Riewald & Lombardo, 2002:3). As a result of the fact that one body side is always more involved in activity than the other side, the opposite extremity or opposite side (the less involved side) will be termed the non-dominant extremity or the non-dominant side. Due to the fact that the terms "dominant" and "non-dominant" sides are critical throughout this study, it is imperative that the criteria for indicating side dominance be determined, as well as the methods by which morphological asymmetry is calculated and expressed.

2.3 CRITERIA FOR DETERMINING SIDE DOMINANCE AND METHODS FOR CALCULATING MORPHOLOGICAL ASYMMETRY

As far as sport participants are concerned, it is obvious that dominance is determined by identifying the primarily involved extremity during the execution of specific sport movements. In cases where this dominance is not obvious from the type of sport movements that are performed (such as with participants of bilateral sports and sedentary individuals), dominance is usually determined by the preferred writing hand, the best throwing arm or the results of tapping tests (Provins, 1997:184). Provins (1997:184) showed that most people are right handed, whilst Dangerfield (1994:9) found that people in general show right hand dominance when performing unilateral tasks. Dangerfield (1994:9) also indicated that hand preference is already apparent at three years of age, but that it is only established at 5-11 years of age.

Just as different criteria exist for the determination of side dominance, so do different criteria and methods exist for the calculation and expression of morphological asymmetry. In his description, Shapovolov (as quoted by Zaharieva 1981:143) regarded morphological asymmetry as a difference of greater than 0.3 cm for a certain limbs' girth, length, breadth or skinfold measurement, when compared to the corresponding limb. One problem with Shapovolov's criteria for morphological asymmetry is that only the prevalence of asymmetry for certain anthropometric measurements can be indicated, whilst the extent to which such asymmetry exists cannot be determined. A more effective method and criteria is the Relative Indices of Asymmetry (RIA) of Wolański (as quoted by Copley, 1980:30), that expresses morphological asymmetry in the form of a numeric value (percentage). The RIA is calculated as follows:

$$RIA = 2(X_D - X_{ND}) / (X_D + X_{ND}) \times 100$$

With: X_D = variable on the dominant side

X_{ND} = variable on the non-dominant side

If RIA is +, then $X_D > X_{ND}$

If RIA is -, then $X_D < X_{ND}$

This equation allows for the differences between the metrical traits of the dominant and non-dominant (or right and left) sides of the body to be expressed as a percentage of the sums of the dominant and non-dominant (or right and left) side traits. By using this equation, bilateral comparisons are made possible by a comparison of the indices of morphological asymmetry of different traits. It is therefore possible to assess the degree of morphological asymmetry that has occurred due to training and/or other inherent or environmental factors. Training, inherent or environmental causes will be discussed once the prevalence of morphological asymmetry amongst different sport participants and normal sedentary individuals has been reported and discussed.

2.4 THE PREVALENCE OF MORPHOLOGICAL ASYMMETRY AMONGST PARTICIPANTS OF DIFFERENT SPORT

The occurrence of morphological asymmetry amongst participants of different sport have been well documented in various studies (Buskirk *et al.*, 1955; Czabanski, 1974; Copley, 1980; Montoye *et al.*, 1980; Zaharieva, 1981; Powers & Walker, 1982; Pirnay *et al.*, 1987; Wyss *et al.*, 1989; Nyström *et al.*, 1990; Swärd *et al.*, 1990; Stretch, 1991; Groppel & Roetert, 1992; Coetzee, 1994; Margonato *et al.*, 1994; Green *et al.*, 1996; Engstrom *et al.*, 1997; Kippers *et al.*, 1998; Krawczyk *et al.*, 1998; Carson, 1999; Engstrom *et al.*, 1999; Jansen van Rensburg, 2000). Due to the differentiation between asymmetrical (unilateral) and symmetrical (bilateral) sport, the research findings of these two sport classifications will be reported and discussed separately.

2.4.1 The prevalence of morphological asymmetry amongst participants of asymmetrical (unilateral) sport

As already indicated, most of the available research on morphological asymmetry in sport focused on tennis players. Buskirk *et al.* (1955), Copley (1980), Montoye *et al.* (1980), Zaharieva (1981), Powers and Walker (1982), Pirnay *et al.* (1987), Wyss *et al.* (1989), Swärd *et al.* (1990), Groppel and Roetert, (1992), Green *et al.* (1996), Krawczyk *et al.* (1998) and Jansen van Rensburg (2000) all reported a high occurrence of morphological asymmetry amongst tennis players.

Table 2.1 summarises the indices of morphological asymmetry amongst tennis players of different age groups, genders and participation levels. From this table it is evident that no significant indices of asymmetry exists for skinfold measurements in the upper body of tennis players (Montoye *et al.*, 1980; Green *et al.*, 1996:945). Earlier research by Copley (1980:312) also confirms these research findings, in that he observed that tennis playing had little effect on the local fat deposits and corresponding skinfold measurements of these players.

More recent research evidence, however, shows that significant ($p < 0.001$) indices of asymmetry do exist for the relaxed upper arm, flexed upper arm, forearm and wrist girths amongst tennis players (Pirnay *et al.*, 1987:332; Green *et al.*, 1996:945; Krawczyk *et al.*, 1998; Jansen van Rensburg, 2000:6), with the dominant side values being greater than that of the non-dominant side. In addition to these findings, Copley (1980:312) reported marked muscle and bone hypertrophy of the dominant upper arm and forearm.

Table 2.1: Summary of the descriptive statistics of indices of morphological asymmetry amongst tennis players of different age groups, genders and participation levels.

Morphological variables	Subject information	Dominant side ($\bar{X}$ ± SD)	Non-dominant side ($\bar{X}$ ± SD)	Indices of asymmetry	Sources
Upper limb skinfolds	61 male players of 55 years or older	No significant differences were found between the dom. and non-dom. side skinfold measurements.			Montoye *et al.* (1980)
Triceps skinfold	8 male players (27.5 ± 2.1 years)	10.7 ± 1.0 mm	9.6 ± 0.6 mm	10.84% (NS)	Green *et al.* (1996:945)
Biceps skinfold		5.0 ± 0.5 mm	4.7 ± 0.5 mm	6.19% (NS)	
Forearm skinfold		6.4 ± 0.9 mm	6.5 ± 0.9 mm	-1.55% (NS)	
Relaxed upper arm girth	10 professional players (20.3 ± 2.1 years)	31.4 ± 1.2 cm	28.1 ± 1.0 cm	11.09% ****	Pirnay *et al.* (1987:332)
	Amongst 134 elite athletes (21-32 years) competing in nine sport disciplines tennis players were found to have the most pronounced asymmetry for certain anthropometric variables, of which the relaxed upper arm girth is one such variable.				Krawczyk *et al.* (1998)
	10 male university players (20.8 years)	30.1 ± 2.80 cm	28.9 ± 2.88 cm	4.07% ****	Jansen van Rensburg (2000:6)
Flexed upper arm girth	10 male university players (20.8 years)	32.5 ± 3.06 cm	31.0 ± 3.13 cm	4.72% ****	Jansen van Rensburg (2000:6)
Upper arm	Marked muscle and bone hypertrophy on the dominant side.				Copley (1980:312)

Table 2.1: Summary of the descriptive statistics of indices of morphological asymmetry amongst tennis players of different age groups, genders and participation levels (continued).

Morphological variables	Subject information	Dominant side ($\bar{X}$ ± SD)	Non-dominant side ($\bar{X}$ ± SD)	Indices of asymmetry	Sources
Forearm girth	10 professional players (20.3 ± 2.1 years)	28.6 ± 1.2 cm	25.3 ± 0.9 cm	12.25% ****	Pirnay *et al.* (1987:332)
	8 male players (27.5 ± 2.1 years)	28.0 ± 0.6 cm	26.2 ± 0.7 cm	6.64% ****	Green *et al.* (1996:945)
	Amongst 134 elite athletes (21-32 years) competing in nine sport disciplines tennis players were found to have the most pronounced asymmetry for certain anthropometric variables, of which the forearm girth is one such variable.				Krawczyk *et al.* (1998)
	10 male university players (20.8 years)	27.7 ± 1.34 cm	26.2 ± 1.68 cm	5.57% ****	Jansen van Rensburg (2000:6)
Forearm	Pronounced muscle and bone hypertrophy on the dominant side.				Copley (1980:312)
Wrist girth	10 professional players (20.3 ± 2.1 years)	18.2 ± 0.7 cm	16.7 ± 0.8 cm	8.60% ****	Pirnay *et al.* (1987:332)
	8 male players (27.5 ± 2.1 years)	17.2 ± 0.3 cm	16.5 ± 0.3 cm	4.15% ****	Green *et al.* (1996:945)
Humerus length	Tennis was proved to cause a slight shortening of the dominant humerus.				Wyss *et al.* (1989)

Table 2.1: Summary of the descriptive statistics of indices of morphological asymmetry amongst tennis players of different age groups, genders and participation levels (continued).

Morphological variables	Subject information	Dominant side ($\bar{X}$ ± SD)	Non-dominant side ($\bar{X}$ ± SD)	Indices of asymmetry	Sources
Forearm length	10 male university players (20.8 years)	45.6 ± 1.60 cm	45.3 ± 1.46 cm	0.66% *	Jansen van Rensburg (2000:7)
Radius length	Tennis playing led to an increase in radius length on the dominant side.				Buskirk *et al.* (1955:129)
Ulna length	Tennis playing led to an increase in ulna length on the dominant side.				Buskirk *et al.* (1955:129)
Humerus breadth (Biepicondylar)	61 male players of 55 years or older	A greater width was found on the dominant side than on the non-dominant side.			Montoye *et al.* (1980)
	8 male players (27.5 ± 2.1 years)	7.1 ± 0.10 cm	7.0 ± 0.01 cm	1.42% (NS)	Green *et al.* (1996:945)
	Amongst 134 elite athletes (21-32 years) competing in nine sport disciplines tennis players were found to have the most pronounced asymmetry for certain anthropometric variables, of which the humerus breadth is one such variable.				Krawczyk *et al.* (1998)
	10 male university players (20.8 years)	7.3 ± 0.38 cm	7.1 ± 0.39 cm	2.78% *	Jansen van Rensburg (2000:6)
Wrist breadth (Bistyloid)	8 male players (27.5 ± 2.1 years)	5.9 ± 0.1 cm	5.7 ± 0.1 cm	3.45% ***	Green *et al.* (1996:945)

Table 2.1: Summary of the descriptive statistics of indices of morphological asymmetry amongst tennis players of different age groups, genders and participation levels (continued).

Morphological variables	Subject information	Dominant side ($\bar{X}$ ± SD)	Non-dominant side ($\bar{X}$ ± SD)	Indices of asymmetry	Sources
Hemithorax perimeter	10 professional players (20.3 ± 2.1 years)	47.6 ± 1.7 cm	47.0 ± 1.4 cm	1.27% (NS)	Pirnay *et al.* (1987:332)
Distal radius trabeculare bone width	10 professional players (20.3 ± 2.1 years)	2.48 ± 0.18 cm	2.08 ± 0.15 cm	17.54% ****	Pirnay *et al.* (1987:333)
Midradius cortical bone width	10 professional players (20.3 ± 2.1 years)	1.77 ± 0.25 cm	1.59 ± 0.13 cm	10.71% ****	Pirnay *et al.* (1987:333)
Forearm volume	8 male players (27.5 ± 2.1 years)	1535 ± 69 ml	1376 ± 79 ml	10.92% ****	Green *et al.* (1996:945)
Humerus cortical area thickness	Tennis was proved to cause an increase of the thickness of the cortical area of the humerus.				Wyss *et al.* (1989)
Total cortical area of the humerus	Tennis was proved to cause an increase in the total cortical area of the humerus, without a reduction of the medullary space.				Wyss *et al.* (1989)
Anterior muscles	A remarkable hypertrophy of the muscles of the anterior compartment was found.				Wyss *et al.* (1989)

* $p < 0.05$
*** $p < 0.005$
**** $p < 0.001$
NS = Not significant.

Wyss *et al.* (1989) also proved that tennis could cause a slight shortening of the humerus on the dominant side, whilst several investigators noted that tennis players experience a statistically significant ($p < 0.05$) increase in their dominant forearm lengths (Jansen van Rensburg, 2000:7), as well as their radius and ulna lengths (Buskirk *et al.*, 1955:129) respectively. It also seems that tennis players show a greater biepicondylar humerus breadth on the dominant side compared to that of the non-dominant side (Montoye *et al.*, 1980; Green *et al.*, 1996:945; Krawczyk *et al.*, 1998; Jansen van Rensburg, 2000:6). Similar findings were also reported by Green *et al.* (1996:945), who found a statistically significantly greater ($p < 0.005$) bistyloid wrist breadth on the dominant side than on the non-dominant side.

No statistically significant indices of morphological asymmetry for the hemithorax perimeter were found by Pirnay *et al.* (1987:332). These researchers did, however, report a statistically significantly ($p < 0.001$) greater dominant trabeculare bone width on the distal mark of the radius and cortical bone width on the midradius mark. Statistically significantly greater ($p < 0.005$) dominant forearm values (Green *et al.*, 1996:945), larger cortical area thickness of the humerus, larger total cortical humerus area and marked muscle hypertrophy of the anterior compartment of the dominant arms (Wyss *et al.*, 1989) were some of the published research findings.

Tennis is certainly not the only asymmetrical sport for which morphological asymmetries that occur due to the unilateral nature of sport movements, have been reported. Nyström *et al.* (1990:138) and Margonato *et al.* (1994:568) (see Table 2.2) have, for example, shown that the girth, cross sectional area and total muscle area of the dominant (forward) thigh of épée fencers are significantly greater than that of the non-dominant (backward) thigh.

Azemar (as quoted by Pirnay *et al.*, 1987:334) examined the effect of épée fencing on the morphological measurements of the upper body and concluded that fencing results in hypertrophy of the dominant shoulder, elevation of the dominant scapula and the development of scoliosis. The fact that these investigators have shown that morphological asymmetries do exist among épée fencers, supports the theory of Nyström *et al.* (1990:138). These researchers indicated that morphological asymmetries may occur amongst these athletes, because their forward extremities (dominant arm and leg) exhibit different movement patterns than that of the backward extremities (non-dominant arm and leg).

Table 2.2: The descriptive statistics of indices of morphological asymmetry amongst épée fencers.

Morphological variables	Forward thigh ($\bar{X}$ ± SD)	Backw. thigh ($\bar{X}$ ± SD)	RIA	Sources
Thigh girth	60.21 ± 1.6 cm	56.8 ± 3.3 cm	5.81% **	Nyström *et al.* (1990:138)
Cross sectional area of thigh (muscle plus bone)	51.7 ± 8.2 cm²	45.8 ± 7.8 cm²	12.1% ****	Margonato *et al.* (1994:568)
Total muscle area of the thigh	The total muscle area of the front thigh is on average 16% (**) higher than that of the backward thigh.			Nyström *et al.* (1990:138)

** $p < 0.01$
**** $p < 0.001$

One sport of particular interest to this study is that of cricket. The tasks performed by cricket players are divided into bowling, batting and fielding, all of which can be regarded as asymmetrical (unilateral) movements. Relatively few studies have, however, addressed the relationship between cricket specific tasks and the morphology of cricketers. In this regard, Stretch (1991:58) indicated that only a limited amount of research on the morphology of cricket players has been conducted and that most of the reported data concerning morphology formed part of broader studies on these subjects. The available literature on morphological asymmetry mostly focused on that of fast bowlers, because of the nature and intensity of bowling which makes them especially prone to such morphological adaptations.

A photo of a high level fast bowler by Bloomfield *et al.* (1994:102) clearly demonstrates the type of asymmetrical upper body development that is commonly seen amongst fast bowlers. Similar results concerning lower body asymmetry were found by Stretch (1991:62-63), who reported that a number of bowlers in his study exhibited a larger calf girth of the leg opposite to the bowling arm, when compared to the leg on the dominant side. He attributed this asymmetrical development to the large impact at front-foot contact during the delivery action and the use of the front leg as a lever during the delivery action. Kippers *et al.* (1998:106) also found (in their study on provincial junior fast bowlers) that small indices of morphological asymmetry exist when the dominant and non-dominant limb measurements of the players are compared. These researchers also recommend that future studies should make use of magnetic resonance imaging to compare limb measurement asymmetry to trunk muscle asymmetry.

According to the author of this study, tennis, épée fencing and cricket are certainly not the only sports that can be classified as asymmetrical sports. Throwing and even jumping items in athletics, i.e. javelin, discuss, shot put, hammer throw, long, triple and high jump, as well as hurdling can also be regarded as asymmetrical items. Other asymmetrical sports includes squash, baseball, softball, volleyball and golf. In spite of the large number of asymmetrical sport types, there has been no published research on the morphological asymmetry of participants of these sports.

To conclude, it is evident that morphological asymmetry is prevalent amongst participants who make use of unilateral activities. This is in accordance with the findings of Zaharieva (1981:148), in which she indicates that morphological asymmetry is more frequently observed in sport where conditions exist for unilateral movements to occur. In contrast to these findings, researchers have also reported that participants of symmetrical sports, such as swimming, exhibit less asymmetrical deviations compared to those participating in asymmetrical sport types (Czabanski, 1974; Zaharieva, 1981; Perrin, 1993; Coetzee, 1994; Krawczyk *et al.,* 1998). It is in the light of these and other findings that a literature survey on the prevalence of morphological asymmetry amongst participants of symmetrical sport is conducted as to enhance the understanding of the relationship between symmetrical development and participation in symmetrical sports.

2.4.2 The prevalence of morphological asymmetry amongst participants of symmetrical (bilateral) sport

In a comparative study on the participants of 14 different sports, Zaharieva (1981:143) found that swimmers had the lowest prevalence of morphological asymmetry. Nearly half of the measured swimmers (49.9%) did, however, portray asymmetry of the upper arm girths. In this specific study, a variable was defined as being asymmetrical when a difference of greater that 0.3 cm between the right and left girths was observed. Coetzee (1994:16) substantiated this finding by reporting very small indices of morphological asymmetry in a study on junior swimmers. Furthermore, Czabanski (1974:211) also concluded that very little limb length asymmetry existed amongst 30 breaststroke swimmers. These findings did, however, suggest that a certain degree of non-significant asymmetrical development does occur amongst swimmers (see Table 2.3). The only non-significant differences that were apparent when comparisons were made between the dominant and non-dominant sides, were the leg length as well as the maximal and minimal calf girth.

Table 2.3: The descriptive statistics of indices of morphological asymmetry amongst breaststroke swimmers (n = 30) (Czabanski, 1974:211).

Morphological variables	Right hand side ($\bar{X}$ ± SD)	Left hand side ($\bar{X}$ ± SD)	Indices of asymmetry
Leg length	91.22 ± 4.43 cm	91.42 ± 4.49 cm	0.22% (NS)
Calf girth (smallest girth)	23.33 ± 0.94 cm	23.30 ± 0.91 cm	0.13% (NS)
Calf girth (greatest girth)	37.20 ± 1.55 cm	37.08 ± 1.65 cm	-0.32% (NS)

NS = not significant

Similar results were also obtained by Perrin (1993:67), who indicated that few morphological differences occurred when the dominant and non-dominant sides of swimmers were compared. These research findings suggest that swimmers develop more symmetrically, which can probably be attributed to the swimming techniques in which both arms and legs are used in a similar fashion (Coetzee, 1994:2).

From the above-mentioned findings, it is, however, also evident that a small degree of asymmetrical development does occur amongst swimmers. Some researchers (Becker, 1986:153; Riewald & Lombardo, 2002:3) have hypothesised that swimmers may indeed exert a greater peak force with one arm or leg compared to the other when performing the propulsion stroke or kick phase during the swimming action. This is probably brought about by the use of unilateral breathing techniques (breathing to one side only) during crawl stroke swimming, which gives rise to asymmetry in the stroke (Riewald & Lombardo, 2002:3; Maglischo, 2003:131). Normal daily activities in which the tendency is to use the dominant side more than the non-dominant side, could possibly also contribute to morphological asymmetries observed amongst these athletes (Dangerfield, 1994:20).

Krawczyk *et al.* (1998) further reported significant levels of asymmetry in other sports (kayaking, canoeing and rowing) which makes use of symmetric movements. These asymmetries were mainly manifested in the forearm girth. Zaharieva (1981:148) observed limb asymmetries in a smaller percentage of the subjects involved in sport in which conditions exist for equal engagement of the opposite limbs, than in participants of sport making use of unilateral activities. In summarising the results of various studies on athletes engaged in symmetrical sports, Krawczyk *et al.* (1998) agreed with the above-mentioned comment by Zaharieva that the left-right differences in anthropometrical measurements recorded in these athletes, were lower than in subjects representing sport making use of asymmetrical movements.

From these results it seems that participants of asymmetrical sports are more prone to asymmetrical development, but that participants of symmetrical sports also show indices of asymmetry for certain morphological measurements. The question now arises whether sedentary individuals also undergo such morphological adaptations, and if so, to what extent?

2.5 THE PREVALENCE OF MORPHOLOGICAL ASYMMETRY AMONGST SEDENTARY INDIVIDUALS

Dangerfield (1994:19) indicated that minor trunk asymmetries (referred to as constitutional back asymmetry) are common amongst the normal population and are frequently detected in school screening programmes. He further noted that the upper limbs display greater indices of morphological asymmetry than the lower limbs. Womersley and Durnin (1973:289) observed no significant differences in the comparison of the dominant and non-dominant skinfold measurements of sedentary individuals, except for the measurements of the triceps skinfold. In this comparison, the measurement on the right hand side was on average 1.2 mm (and statistically significantly) greater than that on the left hand side.

In their study on 58 male épée fencers, Margonato *et al.* (1994:568) used 17 sedentary individuals as control subjects. These researchers reported a 4.32% asymmetry in the forearm cross sectional area, with the dominant side (47.3 ± 2.7 cm^2) being statistically significantly ($p < 0.005$) larger than that of the non-dominant side (43.3 ± 3.5 cm^2). Ruff and Jones (1981:69) also noted that crossed asymmetry exists among sedentary individuals, with the femur on the non-dominant side being slightly longer and heavier (less than 1%) than that of the dominant side. They also reported that the dominant upper limbs of sedentary individuals are statistically significantly longer (1-3%), and heavier (2-4%) than the non-dominant limbs. These findings are further accentuated by the results of Laubach and McConville's (1967:368) study on 117 individuals from the normal population. These researchers found that the upper arm (both relaxed and tensed), forearm and wrist girth, as well as the hand breadth of the right hand side were significantly ($p < 0.01$) larger than that of the left hand side. The measurements for which Laubach and McConville (1967:368) reported significant differences are listed in Table 2.4.

Table 2.4: The descriptive statistics of indices of morphological asymmetry amongst normal individuals (n = 117) (Laubach & McConville, 1967:368).

Morphological variables	Right hand side ($\bar{X}$ ± SD)	Left hand side ($\bar{X}$ ± SD)	Indices of asymmetry
Relaxed upper arm girth	28.71 ± 2.66 cm	28.16 ± 2.62 cm	1.93% **
Tensed upper arm girth	31.56 ± 2.59 cm	30.82 ± 2.59 cm	2.37% **
Forearm girth	26.54 ± 1.54 cm	25.99 ± 1.48 cm	2.09% **
Wrist girth	16.72 ± 0.82 cm	16.58 ± 0.82 cm	2.19% **
Hand breadth	8.49 ± 0.55 cm	8.43 ± 0.52 cm	0.71% **

** $p < 0.01$

Not all studies on morphological asymmetry, however, support a pure environmental and exercise-related explanation for morphological asymmetry. This is shown in a study conducted by Dangerfield (1994:17), in which 100 male neonates of full-term normal birth were measured. Table 2.5 shows small, statistically significant differences between the right and left limb segments for the arm length, forearm length and dorsum hand length of these neonates.

Table 2.5: The descriptive statistics of indices of morphological asymmetry amongst male neonates (n = 100) of full-term normal birth (Dangerfield, 1994:17).

Athropometric variables	Right hand side ($\bar{X}$)	Left hand side ($\bar{X}$)	Indices of asymmetry
Arm length	84.1 cm	84.3 cm	-0.24% *
Forearm length	74.5 cm	75.1 cm	-0.80% **
Dorsum length of the hand	61.0 cm	62.2 cm	-1.95% *****

* $p < 0.05$
** $p < 0.01$
***** $p < 0.0001$

Dangerfield (1994:18), therefore, concluded that the indices of morphological asymmetry in the normal population is mostly very small and considered to be of no functional importance. He did, however, indicate that it's role during the growth process is still unclear.

Now that the nature and incidence of morphological asymmetry amongst sedentary individuals as well as participants of asymmetrical and symmetrical sports have been reported, a report on the factors that can lead to the onset and development of morphological asymmetry will be given.

2.6 THE POSSIBLE CAUSES OF MORPHOLOGICAL ASYMMETRY

Although clinicians consider the musculo-skeletal system to be symmetrical, it is clear from reports that the two sides of the body are not equally at risk to injury and disease (Dangerfield, 1994:10). Wolański (as quoted by Copley, 1980:30) is of the opinion that morphological development is channelled equally to both halves of the body and that a strong functional differentiation of the extremities is needed to disturb the symmetric development. According to Carter (1985:106), morphology can be defined as the science of structure and form without regard to function. He is, however, quick to point out that a basic biological dictum exists, in that form follows function. This implies that function could possibly lead to the onset and occurrence of morphological adaptations such as asymmetries.

Margonato *et al.* (1994:569) clearly show that morphological adaptations and the resulting asymmetries are not strictly related to specific technical training, but that they presumably also reflect the greater use of the dominant arm during normal daily activities. This is also in agreement with the observations of Dangerfield (1994:20), who explained the cause of limb asymmetry amongst sedentary individuals as a greater functional use of the dominant limb compared to the non-dominant limb during daily chores. According to Gomez (1994:47), asymmetrical morphological changes can be accredited to physical activity, environmental factors and/or inherent factors such as laterality, handedness and side dominance. Copley (1980:30) also found that functional, dynamic and morphological asymmetries are largely dependent upon the age, sex and social environment of the subjects under study. In a study by Azemar (1998) in which 1126 specialised sportsmen were measured, cultural factors and gender influences were highlighted as significant contributors to the onset and development of morphological asymmetry. Physical activity was also highlighted by Pirnay *et al.* (1987:331) as one of the most important non-hormonal factors that influence skeletal growth and modifications, such as morphological asymmetries.

As previously mentioned, morphological asymmetry is highly dependent on the kind of sport practised (Zaharieva, 1981:148). There is, therefore a general acceptance that the practised sport as well as the individuals technical level and the number of years of training contributes to the uneven development between the dominant and non-dominant limbs (Margonato *et al.*, 1994:567). Within this context, Stretch (1991:62) observed specific asymmetrical hypertrophy amongst fast bowlers in cricket and attributed this to the many hours spent practising and repetitively performing specific skills. Chvalova *et al.* (1988) also reported asymmetrical differences in the morphology of tennis players and postulated that these asymmetrical changes might have resulted because of the tennis players' asymmetrical training load. There is a further notion by Chvalova *et al.* (1988) that the unilateral trunk rotation and lateral sway exerted by tennis players, might also be responsible for the unequal development of the upper extremity girdle and thoracic musculature. It is also expected that the continued preferential use of selected muscle groups will induce morphological and/or physiological adaptations to the muscles' structure and function (Merletti *et al.*, 1994:2104). Pirnay *et al.* (1987:331) indicate that the demands placed on the locomotor apparatus of athletes making use of asymmetrical movements, could result in developmental and compositional differences between the dominant and non-dominant limbs.

Several studies also suggest that strenuous physical activity can have an effect on bone growth and development (Perrin *et al.*, 1987; Kraemer & Fleck, 1993; Dangerfield, 1994; Green *et al.*, 1996). In this regard, Kraemer and Fleck (1993:11) showed that resistance training stimulates bone development because of the fact that muscle tension and force are increased. It is also clear from the numerous studies conducted on tennis players in which the differences between the dominant and non-dominant sides were observed, that a relationship exist between physical activity and bone growth (Dangerfield, 1994:3). Chronic exercise may, therefore, lead to physical adaptations if the stimulus is of sufficient duration and intensity (Green *et al.*, 1996:946). This is further substantiated by Perrin *et al.* (1987:184) who conclude that neuromuscular adaptation due to participation in asymmetrical sport, does occur.

In summarising the above research findings, two primary mechanisms for the observed bilateral differences exist, i.e. normal extremity dominance (and the resulting asymmetrical development due to daily activities) and asymmetrical morphological development due to participation in sport which makes use of asymmetrical movements. These results with regard to asymmetrical morphological development found amongst participants of asymmetrical sport constitute an incontestable proof of the cause and effect relationship that exists between the functional use of different body parts and the occurring morphological changes that take place.

In some cases, it is, however, difficult to give a conclusive explanation for these observed morphological asymmetries. This is especially evident from the previously mentioned study of Dangerfield (1994:17), in which male neonates of full-term normal birth showed statistically significant asymmetries of the arm length, forearm length and dorsum length of the hand. The causes of this phenomenon are unknown, emphasising the complexity of functional and dynamic lateralisation as indicated by Czabanski (1974:212).

The above literature indicates that different causes of morphological asymmetry exist, as demonstrated by studies on sport participants as well as on sedentary individuals. However, further investigation is also required to establish the possible effects of morphological asymmetry on the health of athletes and sedentary individuals, as well as the possible effects thereof on the performances of these athletes.

2.7 THE EFFECTS OF MORPHOLOGICAL ASYMMETRY ON THE HEALTH AND PERFORMANCES OF ATHLETES

The occurrence of morphological asymmetries amongst athletes and sedentary individuals makes asymmetry an important research subject. This aspect becomes even more important when the negative effects thereof are taken into consideration. In this regard, Starosta (1989) stated that morphological asymmetry could affect the health of athletes negatively, and that it may hinder the achievement of optimal sporting performances.

2.7.1 The possible debilitative effect of morphological asymmetry on the health of athletes and sedentary individuals

Harris (1994:175) observed that concurrent with the rise of organised sport, there has been a dramatic increase in musculo-skeletal injuries (particularly overuse injuries) amongst children, which were previously encountered almost exclusively in adults. The risk of injury to the growth centres of the immature skeleton, as well as the negative effects this has on the overall growth, maturation and psychological well-being of the young athlete are some of the problems that accompany sport participation. Harris (1994:180) and Sallis (1994:223) both reported that overuse injuries account for the majority of sport injuries seen at junior level. Harris (1994:180) described these overuse injuries as microtrauma, which occur insidiously as a result of repetitive musculo-skeletal stress, such as rigorous training and/or the biomechanically incorrect execution of specific techniques in sport. Bloomfield *et al.* (1994:102) further stressed that the overuse of one or several areas of the body could result in many postural defects, which could in turn cause physical discomfort and injury to the athlete.

The strength and mobility demands imposed on the vertebral column in some sport are extreme, with obvious risks of overloading and subsequent injury (Swärd, 1992:358). Together with this, O'Sullivan *et al.* (as quoted by Elliot, 2000:988) noted that the lumbar spine is susceptible to injury under different loading conditions, which could be caused by muscle imbalances. According to Swärd (1992:358), a growing individual's spine is very vulnerable to injuries, especially during the adolescent growth spurt. This was further emphasised by Harris (1994:180-181) who found that the musculo-skeletal system appears to be more vulnerable to injury during the peak height velocity period of adolescence, perhaps due to biomechanical changes that occur during the rapid growth period. This vulnerability is especially evident in young fast bowlers who are prone to sustain such injuries as their musculo-skeletal systems are still immature and not as capable of absorbing the forces associated with fast bowling, as that of more mature players (Elliot *et al.,* 1995:201). The risk of injury to the musculo-skeletal system of young fast bowlers is also increased by the fact that they are often overbowled because of zealous coaches, their inclusion in different squads and their effectiveness in taking wickets (United Cricket Board of South Africa Research Committee, 2000:1).

As a result of these findings, the members of the United Cricket Board of South Africa (UCBSA) Research Committee (comprising of academics, medical doctors, specialists, coaches and ex-players) compiled a screening protocol by which potential injury risk factors of young fast bowlers can be identified. Players are, amongst others, screened for postural defects (i.e. lumbar lordosis, thoracic kyphosis, scoliosis, bow-legs, knock-knees, body asymmetry, and high/flat foot), body weight problems, body development and everyday lifestyle aspects. In the protocol, special attention is also given to asymmetrical body development, muscular size imbalances and altered shoulder or hip heights.

The inclusion of scoliosis as a screening factor in this protocol stresses the importance thereof, and is also in congruence with previous research findings, which have shown that the incidence of scoliosis amongst athletes is fairly high. Scoliosis can be defined as a lateral deviation in the normally straight line of the spine (Miller & Brackman Keane, 1987:1113). The causes of this postural defect can be divided into two categories, namely structural and functional (non-structural) causes (Strydom, 2000:169). According to this classification, structural causes include anatomical defects that a person is born with, whilst functional causes include hyper-dominance and muscle imbalances resulting from one-sided movements. Hauser (as quoted by Becker, 1986:155) conclude that an inability of the back musculature to cope with the required demands of exercise (functional causes) could lead to a deviation in the normal curvatures of the spine and the subsequent onset of scoliosis.

In trying to identify the causes of functional scoliosis, most attention has been given to the paraspinal muscles, apparently under the presumption that the curvature(s) must result from a "bowstring" effort, whereby disproportionate muscle shortening on one side results in concavity on that side (Fuller *et al.*, 1991:144). According to these researchers, "such imbalances could result from an absence of the "cross-training effect" in which the over-development of muscles on one side is not adequately matched by similar development of the muscles on the other side". However, since most studies have not yet shown that significant differences do exist between the transverse muscles of both sides, it cannot be said conclusively that muscle imbalances cause these curvatures. As has been shown in most studies regarding scoliosis, it is virtually impossible to differentiate absolutely between the potential aetiologies and the consequences of scoliosis (Fuller *et al.*, 1991:147).

One study in which a very high prevalence of scoliosis (>80%) amongst participants of sports in which movements occur where an asymmetrical load is placed on the trunk and shoulders, such as javelin and tennis, was that of Swärd (1992:362). This high incidence of scoliosis was also found by Kuprian *et al.* (1994:312), who reported a high incidence of functional scoliosis amongst those athletes participating in sport that requires extreme torque production in repetitive serving, throwing, and volleying motions such as archers, javelin throwers, pole-vaulters and table tennis players. A study by Krahl and Steinbruck (as quoted by Becker, 1986:150) did, however, conclude that only 33.5% (191) of the 571 tested athletes in their study appear to have functional scoliosis, whilst 1.6% (9) showed signs of idiopathic scoliosis. It should, however, be remembered that the observation of asymmetry of the back area of an athlete does not necessarily imply that the athlete has scoliosis (Swärd, 1992:362).

Although scoliosis is more likely to occur amongst participants of asymmetrical sport, Sallis (1994:225) indicated that scoliosis is quite common amongst younger swimmers and that scoliosis may even be aggravated by swimming. Becker (1986:149) found that persons involved in swimming from a young age are exposed to the types of stress that can affect growth and development of their maturing musculo-skeletal systems in an adverse way, leading to a disruption of the normal growth pattern. In a study conducted on 173 male and 193 female swimmers, Becker (1986:151) showed that 16% of the swimmers had mild functional scoliosis, whilst 6.9% showed structural idiopathic signs of scoliosis. These incidence figures are 3½ times higher than the incidence of scoliosis amongst normal sedentary individuals. Becker (1986:156) noted further that prevalent functional scoliosis in swimmers is often accompanied by the over-development of one of the upper extremities. In fact, all of the swimmers with mild functional scoliosis (16% of the total tested group) displayed a lateral curvature to the dominant side of the body. Becker (1986:155) also reported that the presence of scoliosis amongst swimmers might be indicative of asymmetrical motor development patterns that could have influenced the growth of the vertebrae negatively. It is, however, clear that the incidence of scoliosis amongst swimmers (16%) (Becker, 1986:151) is much lower than is the case with participants of asymmetrical sport types (>80%) (Swärd, 1992:362).

Scoliosis is, therefore, clearly prevalent amongst participants of both asymmetrical and symmetrical sport. Further evidence suggests that scoliosis is also prevalent amongst 14.4% and 18.9% of the boys and girls from the sedentary population respectively (Willner, 1984:645).

Therefore, movement asymmetries in sport (different sides of the body exerting different movement patterns) can sometimes contribute to the onset and development of postural defects, such as scoliosis. Another contributing factor in this regard is the overuse of certain muscle areas, as outlined in this section. From the above results, one may argue that a correlation exists between such postural defects and morphological asymmetries and the health of the individual, although the precise mechanisms with regard to morphological asymmetry is not yet fully understood. Of further importance are the possible negative effects that morphological asymmetry may have on the achieved performance of the athlete. The following section will address this possibility.

2.7.2 The possible performance-limiting effect of morphological asymmetry on athletes

Surprisingly, very little research has examined the possible performance-limiting effect of morphological asymmetry on athletes. In fact, the only direct reference to the negative consequences of morphological asymmetry is the statement by Starosta (1989) that "optimal performance in sport is hindered by morphological asymmetry". It can, however, be argued that any health debilitating consequence of morphological asymmetry (as discussed in the previous section), will negatively affect sporting performances. No studies have, however, been conducted to prove the possible negative effect of morphological asymmetry on performance.

It should, however, be noted that asymmetry is not limited to morphological development only. Starosta (1989) also observed that morphological asymmetry prevents full range of movement development. Various researchers have focused their attention on the asymmetrical development (differences between the dominant and non-dominant sides) of certain flexibility (Chinn *et al.*, 1974; Copley, 1980; Elliot *et al.*, 1986; Chandler *et al.*, 1990; Magnusson *et al.*, 1994; Jansen van Rensburg, 2000) and strength variables (Chinn *et al.*, 1974; Powers & Walker, 1982; Buti *et al.*, 1984; Nyström *et al.*, 1990; Groppel & Roetert, 1992). The results of studies concerning non-morphological asymmetries will not be discussed due to the fact that the focus of this study is on morphological asymmetry.

The lack of research on this topic emphasises the need for further examination of the possible relationship between non-morphological asymmetries and morphological asymmetries and the combined effects of these two variables on performance. Results regarding this last mentioned field would be of great interest and benefit to the sporting fraternity.

When both the high incidence of morphological asymmetries amongst athletes as well as the negative effects thereof are taken into account, it is clear that the need for a scientific prevention and remedy measure cannot be over accentuated. In the next section, a closer look will be given to the preventive and remedial measures that are currently available for athletes with high indices of morphological asymmetry.

2.8 THE PREVENTION OF AND REMEDY FOR MORPHOLOGICAL ASYMMETRY

A number of authors have made recommendations concerning the implementation and identification of scientific preventive and remedial measures for morphological asymmetry. In this regard, Carson (1999:105) firstly called for a greater collaboration between the different exercise professionals and coaches (and for that matter all of the different role-players in sport) in order to promote good posture and body alignment in young athletes. Kelly (1995:312) and Finch *et al.* (1999:269) also stressed the importance of implementing ways to ensure the correct execution of movement patterns during training. Carson

(1999:105) stated that such collaboration (with the emphasis placed on correct movement patterns and body posture) may contribute significantly towards the development of good joint mechanics and movement patterns. This may, in turn, translate into good technique and a lower prevalence of morphological asymmetries and injuries amongst athletes.

In addition to these preventive measures, Groppel and Roetert (1992:260) recommend that athletes such as tennis players, should also incorporate flexibility, strength and endurance training into their fitness regimen, to minimise morphological asymmetry and injuries, while simultaneously enhancing performance. In this regard, the results of Harvey's study (1998) suggest that flexibility exercises can be successfully used to decrease the incidence of morphological asymmetry amongst athletes.

Research has shown further that therapeutic exercises can significantly contribute to the correction of any existing muscular or postural imbalances (Groppel & Roetert, 1992:262; Drowatzky & Woods, 1997; Strydom, 2000:169). In cases where muscle imbalances and morphological asymmetry are present, Norris (1995:134) emphasises the necessity to correct such muscle imbalances before engaging in general strengthening programmes of the lumbar spine. Together with these research findings, Fuller *et al.* (1991:147) noted that an aggressive physical therapy, by which an attempt is made to create an unbalanced pull from the concave side of the transverse musculature, may reduce the progression of postural defaults. According to Kelly (1995:312), such physical therapy methods are, however, only suitable for the treatment of functional (non-structural) scoliosis, as no deformity of the spine exists. He indicated further that such deviations of the vertebrae (scoliosis) could be realigned through positioning and/or removal of the primary cause, such as muscle weaknesses.

Swimming (as mentioned in Section 2.4.2) might also be seen as a useful preventive or therapeutic exercise for morphological asymmetry. Since swimming does not involve any hard impact and buoyancy produces a significant reduction in body weight, the joints are protected from excessive exertion (Barteck *et al.*, 1999:185). The water in which the swimmers are immersed, furthermore, promotes blood circulation (Barteck *et al.*, 1999:185). Swimming also involves all the major muscle groups and leads to an increase in muscle flexibility (Moran & McGlynn, 1997:24) and cardiorespiratory fitness (Anon., 2003:1). These last mentioned benefits, together with the fact that swimming is a bilateral activity of which its participants show very few indices of morphological asymmetry, make it an ideal preventive exercise for morphological asymmetry.

2.8.1 Swimming as a possible preventive or therapeutic exercise for morphological asymmetry

The role of swimming as a preventive or therapeutic exercise for the treatment of morphological asymmetry and scoliosis is a debatable issue. Despite contradicting research findings, researchers like Preislerova (1987) and Kuprian *et al.* (1994:320) support the notion that swimming can be used successfully in rehabilitation programmes for scoliotics. Kuprian *et al.* (1994:320) do, however, also point out that a high incidence of unilateral trunk rotation and lateral sway, which can lead to unequal development of the upper body together with the thoracic musculature, are sometimes experienced by swimmers. This last mentioned point together with the findings of Becker (1986:157) and Sallis (1994:225), which indicate that swimming has a significant effect on the reversal of unilateral spine alignment, stresses the need for further research into this aspect. In the meantime, the emphasis must be placed on the correct and supervised implementation of techniques (such as swimming) that reduce any possible forthcoming negative effects of asymmetry on the health and performances of athletes.

2.9 SUMMARY OF THE LITERATURE

The literature study on morphological asymmetry amongst sport participants and sedentary individuals pointed to the relationship between human morphology and functioning, and the implications thereof on sporting performance. The emphasis of this study falls on a related morphological topic, that of the morphological asymmetry found amongst fast bowlers, crawl stroke swimmers and sedentary individuals. Research on this topic is of the utmost importance due to the current shortage of literature findings on this topic and the possible effects of morphological asymmetry on the health and performances of athletes.

The occurrence of morphological asymmetry amongst participants of asymmetrical (unilateral) sport such as tennis, épée fencing and cricket (fast bowlers) has been reasonably well documented. Significant indices of asymmetry exist for various morphological variables amongst these athletes. Most of these morphological asymmetries occur in the upper extremities, with the dominant side girths being larger than that of the non-dominant side.

Small morphological asymmetries were also found to be prevalent amongst swimmers (participants of a symmetrical/ bilateral sport), albeit to a lesser extent than with participants of asymmetrical sports. A possible explanation for the prevalence of smaller morphological asymmetries amongst swimmers, may be related to the tendency to use the dominant extremities more than the non-dominant extremities during normal, daily activities and the use of unilateral breathing and stroke patterns during swimming training.

There is further evidence that morphological asymmetries are even prevalent amongst sedentary individuals, again emphasising the greater functional use of the dominant limb compared to the non-dominant limb during normal daily activities. Numerous other factors that can contribute to the onset of morphological asymmetries were also discussed. Amongst these factors, the role of age, gender, social environment, cultural factors and physical activity or participation in certain sport were discussed in the literature review.

Another aspect of morphological asymmetry not to be overlooked is the possible influence that this morphological factor can have on the health and performance of athletes. Although a conclusive indication that morphological asymmetry has a direct impact on the athletes' health may not be made, morphological asymmetry may contribute to this situation in that certain postural defects can develop due to asymmetrical techniques and overuse. Postural defects such as scoliosis may, in turn, cause physical discomfort and injury, which may have a further negative effect in that it may prevent optimal performances in the sport.

Although swimmers do portray indices of morphological asymmetry, these indices are mostly very small. It can, therefore, be argued that swimming might be an excellent preventative and remedial exercise in cases where the possibility exists that morphological asymmetry may develop, or where morphological asymmetry is already prevalent. One apparent reason for this is that swimming is a bilateral exercise in which both sides of the body are used in a similar fashion. In addition to this, swimming has additional advantages for conditioning and remedial purposes, which makes it an ideal exercise for the prevention and remedy of morphological asymmetry.

In spite of the fact that the prevalence of morphological asymmetry amongst athletes and sedentary individuals is rather high, and that morphological asymmetry has a debilitative effect on the health and performances of athletes, this has been a research area that has not received much attention during the last few years. It is, therefore, necessary to investigate the prevalence of morphological asymmetry amongst participants of asymmetrical (unilateral) and symmetrical (bilateral) sport. In this regard, the author decided to focus on the prevalence of morphological asymmetry amongst fast bowlers and crawl stroke swimmers. Aged-matched sedentary individuals were also included in this investigation to determine the effect of chronic exercise on the morphological asymmetry of athletes. It is in the light of this literature survey that the results of this investigation follow.

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3 Asymmetry in the upper body of high school fast bowlers in cricket in South Africa

Prof. J. Hans De Ridder presented this article in poster format at the 2000 Pre-Olympic Congress in Brisbane, Australia. The abstract of this poster was included in the Congress book of abstracts.

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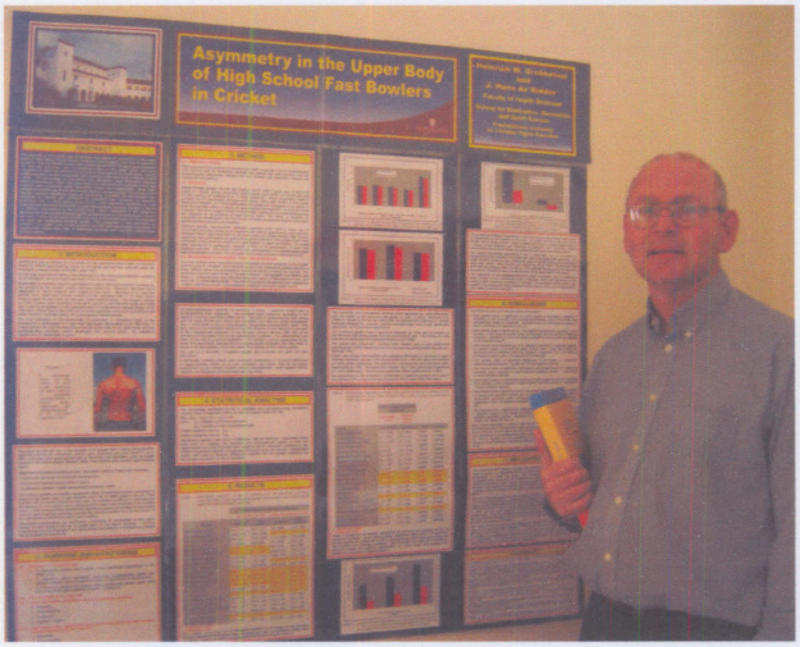
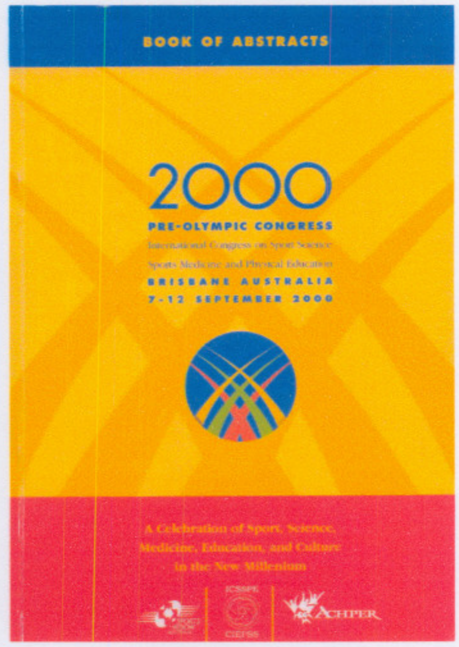
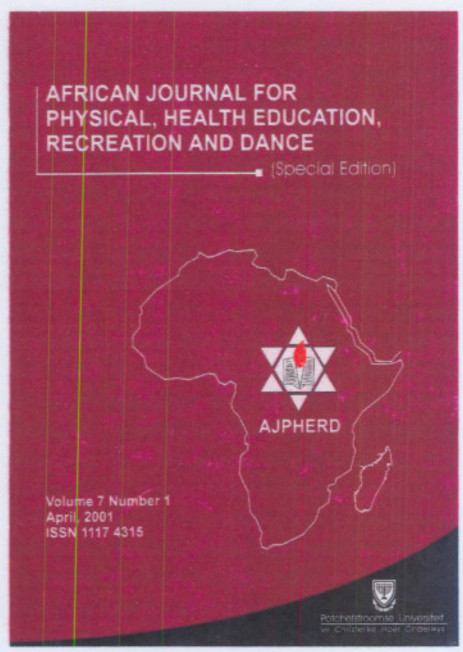




A photograph depicting Prof. Hans De Ridder with the poster he presented during the 2000 Pre-Olympic Congress in Brisbane, Australia. The Congress book of abstracts is featured on the right hand side.



A photograph of Prof. Hans de Ridder, Mr. Heinrich Grobbelaar and the African Journal for Physical, Health Education, Recreation and Dance.

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ASYMMETRY IN THE UPPER BODY OF HIGH SCHOOL FAST BOWLERS IN CRICKET IN SOUTH AFRICA

H. W. Grobbelaar and J. H. De Ridder

The purpose of this study was to compare the indices of morphological asymmetry in the upper body of high school South African cricketers (fast bowlers) with that of sedentary individuals. Fast bowlers (n = 27) with a mean age of 16.5 ± 1.16 years were measured and compared to sedentary individuals (n = 27) with a mean age of 16.1 ± 0.82 years. The twenty one anthropometric variables measured were primarily those described in Norton and Olds (1996:25-73) and were measured twice on both the dominant and non-dominant sides. The indices of morphological asymmetry were calculated using Wolański's Relative Indices of Asymmetry (RIA). The measurements of the fast bowlers' dominant and non-dominant sides were compared using dependent t-tests. The group of fast bowlers' showed significant ($p < 0.001$) indices of asymmetry, for the relaxed (3.8 ± 2.30%), tensed (4.7 ± 2.16%) and corrected (4.7 ± 2.29%) upper arm girths, forearm (2.8 ± 2.3%) and half-chest girths (6.4 ± 3.19%). The mid-axilla (4.8 ± 9.27%) and supraspinal skinfolds (8.1 ± 13.06 %), as well as the bi-epicondylar humerus breadth (1.8 ± 2.73%) differed significantly ($p < 0.05$). When compared to the sedentary individuals (by means of an independent t-test), the fast bowlers showed significantly greater indices of morphological asymmetry for the relaxed upper arm, tensed upper arm and half-chest girths ($p < 0.001$), and for the corrected upper arm girth and hand length ($p < 0.05$). The conclusion is made that morphological asymmetries is prevalent in the upper bodies of fast bowlers and that these indices of morphological asymmetry is significantly larger than that of sedentary individuals, with possible health debilitative and performance-limiting effects.

Key words: Asymmetry, fast bowlers, cricket, sedentary individuals, South Africa

INTRODUCTION

Asymmetry can be defined as "the relation of two quantities that have no common measure", whilst asymmetrical refers to "not being symmetrical, with the parts not arranged correspondingly" (Onions, 1980). Strydom (1990) divided the causes of morphological asymmetry into two categories, i.e. structural and functional (non-structural) causes. Strydom (1990) indicated further that structural asymmetry refers to a defect with which a person is born, whilst functional causes include hyper-dominance and muscle imbalances resulting from one-sided movements, by which the body continuously bends to one side, or in which one side is continuously used. In this regard Pirnay, Bodeux, Crielaard and Franchimont (1987) note that the asymmetrical demands on the locomotor apparatus of the dominant limb compared to the non-dominant limbs, lead to the development of the dominant limbs that differ from that of the non-dominant limb, commonly regarded as morphological asymmetry.

Numerous studies with regard to morphological asymmetry have been conducted on tennis players, in which morphological asymmetry of the upper-body was frequently reported. Wyss, Gandini, Levi, Astegiano, Ganzit and Vaudano (1989) proved that tennis causes a shortening of the humerus on the dominant side. Montoye, Smith, Fardon and Howley (1980) further indicated a greater bone width on the dominant side for the ulna, radius and humerus of tennis players. Green, Fowler, O'Driscoll, Blanksby and Taylor (1996) reported significant differences for forearm volume ($p < 0.005$), forearm girth ($p < 0.001$), wrist girth ($p < 0.001$) and bistiloid width ($p < 0.005$), with the dominant side being greater on each occasion.

Observable morphological asymmetries were also reported for participants of other asymmetrical sports such as épée fencing and cricket (fast bowlers). Margonato, Roi, Cerizza and Galdabino (1994) found significant differences ($p < 0.001$) between the dominant and non-dominant sides of the forearm cross-sectional area in a group of 58 male épée fencers.

From a morphological viewpoint, very little information was found with regard to morphological asymmetry of fast bowlers. Stretch (1991) reported that in a number of the fast bowlers in his study, the leg opposite the dominant bowling arm showed greater calf girth measurements than that on the dominant side. A photograph in Bloomfield, Ackland and Elliot (1994) clearly portrayed the over-development of the dominant side of the upper body of a high level fast bowler, which also showed accompanying scoliosis. In addition to these findings, Kippers, Engstrom, Walker and Hunter (1998) state that indices of limb asymmetry (although very small) do exist. These researchers also emphasised the need for further studies, in which these asymmetric limb measurements and asymmetries of the trunk muscles be compared (by making use of magnetic resonance images), to determine the possible contribution thereof towards back injuries in this population.

The apparent reason for such studies is emphasised further by the results of Engstrom, Walker, Kippers, Hunter, Hanna and Buckley (1999), who reported large and reliable asymmetries in fast bowlers for the quadratus lumborum muscle volume (ÅX = 10% absolute volume asymmetry, effect size 1.2). These researchers indicate further a strong association between stress injuries of the pars and asymmetry of the quadratus lumborum (>10%) on the bowling arm side (relative risk Å4.0). It is, therefore, hypothesised that asymmetric volumes of the quadratus lumborum muscle, underlie asymmetric loading in the pars, hence indicating it as a possible contributing factor to the complex aetiology of bone stress injuries of the pars commonly found in fast bowlers.

According to Stretch (2000), most of the injuries to fast bowlers occur as a result of over-bowling, poor technique or a combination of these two factors. Swärd (1992) also indicated the high vulnerability of the growing individuals' spine to injuries, especially during the adolescent growth spurt. According to Stretch (2000), this is a period when young fast bowlers are especially prone to be over-bowled, with resulting injuries that could have a great impact on the player at a later stage. Swärd (1992) subsequently reported a scoliosis frequency of more than 80% amongst the participants of sport in which movements occur where an asymmetrical load is placed on the trunk and shoulders, such as javelin and tennis. Fast bowlers show similar asymmetrical loads.

As a result of these findings and the high occurrence of back injuries to young fast bowlers, the United Cricket Board of South Africa (UCBSA) Research Committee (2000:1) was formed to address the issue of back injuries to cricket players and, in particular, to young fast bowlers. This committee compiled a screening protocol by which potential injury risk factors in young developing fast bowlers can be screened. This protocol includes postural defects (i.e. lumbar lordosis, thoracic kyphosis, scoliosis, bow-legs, knock-knees, body asymmetry, and high/flat foot arches), bodyweight problems, body development and everyday lifestyle habits. According to this protocol, when screening for body asymmetry, attention must be paid to asymmetrical body development, muscular size imbalance, altered shoulder or hip height and the possible prevalence of scoliosis. The importance of screening for morphological asymmetry is, therefore, shown, but little research has been done on young fast bowlers to investigate to what extent it is prevalent, and how it can be prevented or remedied.

From the above mentioned research results, it is evident that indices of morphological asymmetry are prevalent amongst participants of asymmetrical sport such as tennis, épée fencing and cricket (fast bowlers). Morphological asymmetries have, however, also been reported for sedentary individuals (Laubach & McConville, 1967; Womersley & Durnin, 1973; Ruff & Jones, 1981; Margonato *et al.*, 1994). The apparent reasons for this occurrence is the greater functional use of the dominant limb compared to the non-dominant limb during the execution of normal daily activities (Dangerfield, 1994; Margonato *et al.*, 1994).

The first question that arises is whether morphological asymmetry is found in the upper body of fast bowlers (and if so, to what extent does it occur), as there is clearly a gap in the literature on this subject and this particular position in cricket. Fast bowlers are to be studied because they show the greatest tendency of all cricketers towards asymmetrical development because of the nature and intensity of the bowling action. The second question is whether fast bowlers show significantly greater indices of morphological asymmetry than sedentary individuals. If the fast bowlers show statistically significantly greater indices of morphological asymmetry than the aged-matched sedentary individuals, one could assume that it is as a result of the asymmetrical technique used in fast bowling. Information on the occurrence of morphological asymmetry in the upper body of fast bowlers could be of great value to the Sport Scientist, Biokineticists, Physiotherapists and other role-players within the sporting context. Exercise programmes could then be developed and implemented accordingly to prevent or remedy the occurrence of morphological asymmetry, whilst they can also contribute to improved performances.

METHODS

Subjects

All the fast bowlers (n = 27) with a mean age of 16.5 ± 1.16 years, in a South African provincial cricket squad (u/15 (n = 9), u/17 (n = 8) and u/19 (n = 10)), batting at numbers 8 to 11 were measured. While reasonably small in number, this is a particularly homogenous group. Other fast bowlers in the squad, batting at numbers 1 to 7 (all-rounders), were deliberately excluded from the tested group in order to limit the possible effect which batting may have on asymmetrical development. It must be noted, however, that quite a number of these bowlers are regarded as all-rounders at high school and club level.

Eighty male high school pupils (of the same age group as the fast bowlers) were asked to complete the Sport Participation Activity Profile Questionnaire (SPAPQ). From these results, the lifestyles of thirty five pupils were regarded as sedentary. In addition to their sedentary lifestyle, none of these pupils have ever participated in any asymmetrical sport, thereby enabling them to form part of the control group for this study. From these thirty five pupils, twenty seven (with a mean age of 16.1 ± 0.82 years) were randomly chosen and tested, in order to determine natural asymmetric development.

Measurement procedures and anthropometry

The subjects were informed about the nature of the measurements and were free to refuse to participate in the study. All of the fifty four subjects completed informed consent forms.

The fast bowlers were measured prior to their scheduled practice sessions at the facilities of the Cricket Union. Demographic information and a sport participation history of the fast bowlers' were also gathered. The fast bowlers were measured prior to participation in any physical activities or warm-up routines. After being included in the control group by means of the SPAPQ results, the sedentary individuals were measured in the exact same way as the fast bowlers.

Eighteen anthropometrical variables (eight skinfolds, five girths, three segment lengths and two bone breadths) were measured. From these measurements the sum of the eight skinfolds, upper limb length and corrected arm girth were derived, bringing the total number of variables to twenty one. Two sets of measurements were taken for each variable, of which the mean value was used for further analysis. These variables were measured according to the methods described by Norton, Whittingham, Carter, Kerr, Gore and Marfell-Jones (1996:25-73).

One of the measured girths (the half-chest girth) is not an internationally recognised anthropometric girth. This measurement can be defined as the horizontal distance from the midpoint of the sternum on the level of the mesosternal landmark to the spinous process of the vertebrae on the same level as the mesosternal landmark, taken at the end of a normal expiration. It was specifically developed by the authors of this study to measure the possible morphological asymmetry in the upper body, as seen amongst various sport participants.

A Harpenden skinfold caliper (with a constant compression of 10 $g.mm^{-2}$), large sliding caliper, segmometer, stadiometer, small sliding (bone) caliper and steel anthropometry tape were used for the measurements.

Data analysis

The indices of morphological asymmetry of the twenty one measurements were calculated using Wolańskis' Relative Indices of Asymmetry (RIA), as used by Copley (1980), in which:

$$RIA = 2(X_D - X_{ND}) / (X_D + X_{ND}) \times 100$$

With: X_D = variable on the dominant side and X_{ND} = variable on the non-dominant side

If RIA is +, then $X_D > X_{ND}$. If RIA is -, then $X_D < X_{ND}$.

This equation allows for the differences between the metrical measurements of the dominant and non-dominant sides of the body to be expressed as a percentage of the sums of the dominant and non-dominant side measurements, thereby, enabling direct comparisons of the indices of morphological asymmetry of different measurements (Copley, 1980).

The Statistica data Processing package (StatSoft Inc. 2000) was used to process the data. Descriptive statistics are reported for all the measurements. Dependent *t*-tests were used to compare the dominant and non-dominant values of both the fast bowlers and sedentary individuals (regarding the twenty one measured variables) to see whether significant differences were prevalent in the two groups. Independent *t*-tests were used to measure differences between the two groups regarding the relative indices of asymmetry of the twenty one variables.

RESULTS AND DISCUSSION

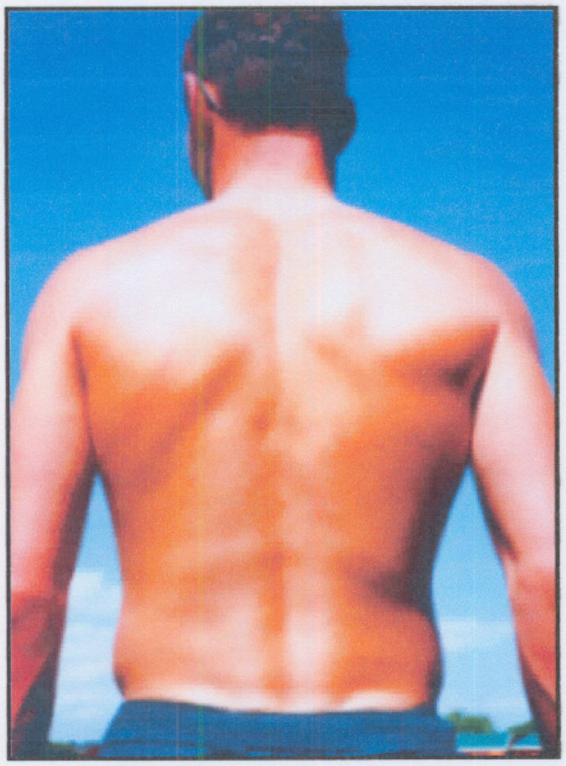

Figure 1: A photograph depicting the upper body of a provincial fast bowler, in which hypertrophy and over-development of the dominant right-hand side is evident.

Figure 1 is a photograph of one of the tested fast bowlers. From this photo it is evident that the dominant right-hand side has undergone hypertrophy and over-development. Table 1 further reports that eight of the measured upper body variables in the group of fast bowlers, showed statistically significant differences when the dominant and non-dominant side values were compared. These eight variables are graphically illustrated in Figures 2 and 3.

The mid-axilla and supraspinal skinfolds of the fast bowlers show a significant ($p < 0.05$) difference, with the values on the dominant side greater on each occasion. In this regard, Martorell, Mendoza, Mueller and Pawson (1988) indicated that differences in skinfold thickness between the dominant and non-dominant sides, even though statistically significant, are of no practical significance. The relaxed upper arm*, flexed upper arm*, corrected upper arm, forearm and half-chest* girths show significant ($p < 0.001$) differences, with the dominant side being greater than the non-dominant side. The three girths marked with an asterisk are the same girths for which significant differences were observed between the fast bowlers and the sedentary individuals and will be discussed later.

Table 1: The descriptive statistics of the dominant and non-dominant sides of the fast bowlers and the age-matched sedentary individuals.

	Mean values and standard deviations			
	Fast bowlers (n = 27)		Sedentary individuals (n = 27)	
VARIABLES	**Dominant**	**Non-dominant**	**Dominant**	**Non-dominant**
SKINFOLDS (mm)				
Biceps skinfold	5.6 ± 1.78	5.9 ± 1.72	6.3 ± 2.64	1.72 ± 3.32
Triceps skinfold	10.2 ± 3.43	10.0 ± 3.33	13.2 ± 5.48 *	12.1 ± 4.77 *
Subscapular skinfold	9.6 ± 2.37	10.0 ± 2.58	11.3 ± 5.86	11.6 ± 5.23
Pectoral skinfold	7.1 ± 2.33	6.6 ± 2.24	8.1 ± 4.69	7.9 ± 4.16
Mid-axilla skinfold	7.7 ± 2.21 *	7.4 ± 2.15 *	9.2 ± 4.18	9.5 ± 4.86
Supraspinal skinfold	8.9 ± 2.95 *	8.3 ± 3.42 *	10.3 ± 5.57	10.1 ± 5.17
Iliac crest skinfold	11.0 ± 3.91	11.2 ± 4.27	14.9 ± 7.50	14.7 ± 7.41
Abdominal skinfold	11.5 ± 3.88	11.2 ± 4.27	11.6 ± 4.47 **	10.8 ± 4.03 **
Sum of 8 skinfolds[a]	71.5 ± 19.10	70.6 ± 19.60	85.0 ± 35.20	83.5 ± 33.70
GIRTHS (cm)				
Relaxed upper arm girth	30.0 ± 3.27**	28.9 ± 3.29**	28.8 ± 3.17 *	28.5 ± 3.29 *
Flexed upper arm girth	31.8 ± 3.32**	30.3 ± 3.40**	30.7 ± 3.03 **	30.0 ± 3.22 **
Corrected upper arm girth	30.7 ± 3.15**	29.3 ± 3.22**	29.3 ± 2.64 *	28.8 ± 2.87 *
Forearm girth	27.3 ± 2.15**	26.6 ± 1.99**	26.4 ± 1.90 **	25.9 ± 1.87 **
Wrist girth	17.7 ± 0.88	17.7 ± 1.04	17.6 ± 1.10 *	17.4 ± 1.07 *
Half-chest girth	49.3 ± 4.17**	46.2 ± 3.73**	46.8 ± 3.75 **	45.5 ± 3.71 **
LENGTHS (cm)				
Upper arm length	34.8 ± 2.74	35.2 ± 1.85	34.4 ± 2.92	34.3 ± 2.89
Forearm length	26.1 ± 1.35	25.9 ± 1.39	25.4 ± 1.82	25.3 ± 1.86
Hand length	19.9 ± 1.09	19.8 ± 1.02	19.6 ± 1.13	19.7 ± 1.20
Upper-limb length	80.8 ± 4.53	80.8 ± 3.78	79.3 ± 5.62	79.3 ± 5.72
BREADTHS (cm)				
Humerus breadth	7.2 ± 0.49 *	7.1 ± 0.46 *	7.2 ± 0.39 **	7.0 ± 0.49 **
Wrist breadth	5.9 ± 0.45	5.8 ± 0.47	5.6 ± 0.33	5.7 ± 0.35

[a] Sum of 8 skinfolds = biceps, triceps, subscapular, pectoral, mid-axilla, supraspinal, iliac crest, abdominal.

* $p < 0.05$

** $p < 0.001$

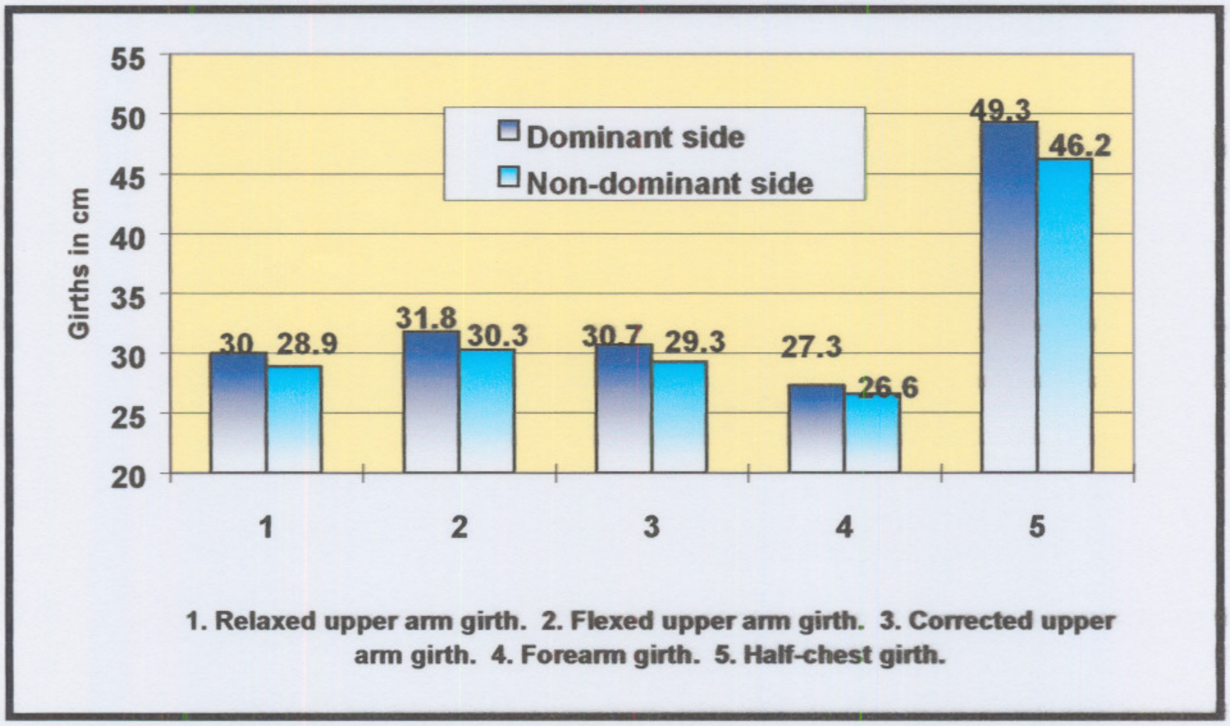

Figure 2: Graphs of the five variables for which the fast bowlers (n = 27) showed significant ($p < 0.001$) differences between the dominant and non-dominant side measurements.

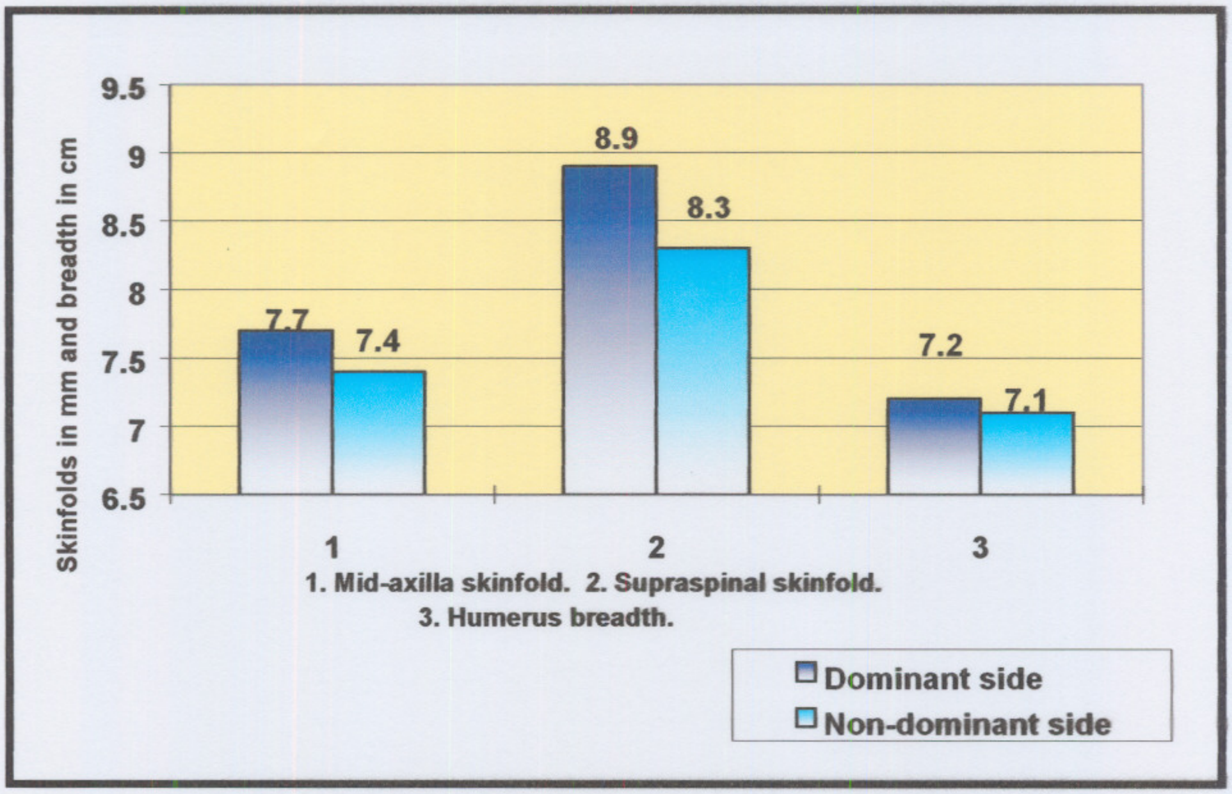

Figure 3: Graphs of the three variables for which the fast bowlers (n = 27) showed significant ($p < 0.05$) differences between the dominant and non-dominant side measurements.

The humerus breadth of the fast bowlers shows a significant difference ($p < 0.05$), with the breadth on the dominant side being greater than that on the non-dominant side. This finding is in line with that found amongst tennis players as reported by Montoye *et al.* (1980).

According to Table 1, nine of the variables in the group of aged-matched sedentary individuals showed significant differences between the dominant- and non-dominant sides. These observed asymmetries again reflect on the greater functional use of the dominant side during daily activities as indicated by Dangerfield (1994) and Margonato *et al.* (1994).

Table 2 reports on the indices of morphological asymmetry, the t-values and p-values for the twenty one measured variables of both tested groups, from which the comparisons between the two groups in this study are made. The five variables for which significant differences were observed are also graphically illustrated in Figures 4 and 5.

Significant differences in the relative indices of morphological asymmetry for the relaxed upper arm, flexed upper arm, and half-chest girths ($p < 0.001$) were noted between the groups of fast bowlers and sedentary individuals. The corrected upper arm girth and hand length also differed significantly ($p < 0.05$).

The greater relative indices of morphological asymmetry found in the upper arms of the fast bowlers compared to the sedentary individuals are the result of hypertrophy of the muscles in this area due to the fast bowling action. The major muscles in this area are m biceps and m triceps brachii, all of which are prone to undergo hypertrophy as a result of the intensity and frequency of eccentric and concentric muscle contractions during elbow flexion and extension. The greater relative indices of morphological asymmetry of the half-chest girth of the fast bowlers can be accredited to hypertrophy of the muscles on the dominant side of the upper back and chest. The major muscles in this area are m latissimus dorsi, m erector spinae and m pectoralis major and minor, which are all involved in the fast bowling action. This particular finding was expected, because of the portrayed over-development of the upper body in this area by Bloomfield *et al.* (1994), hence leading to the development of the half-chest girth measurement.

The observed morphological asymmetry of the hand length of the fast bowlers can be accredited to the continuous force exerted on the metacarpal bones, phalanxes, joints and ligaments of the bowling hand caused by the momentum of the ball. The momentum is the result of the weight of the cricket ball (156 g) multiplied by the velocity of the hand as the bowling arm rotates around the shoulder during the bowling action.

Table 2: Indices of morphological asymmetry, t-values and p-values (of the 21 variables) for the fast bowlers and the age-matched sedentary individuals.

	Mean values and standard deviations			
	Fast bowlers (n=27)	Sedentary individuals (n=27)		
Variables	**Indices of asymmetry (%)**	**Indices of asymmetry (%)**	**t-value**	**p-value**
SKINFOLDS				
Biceps skinfolds	-5.5 ± 13.50	-6.9 ± 30.47	1.90327	0.62547
Triceps skinfolds	2.0 ± 14.92	7.8 ± 11.61	-1.60345	0.114893
Subscapular skinfolds	-3.7 ± 11.28	-4.1 ± 9.76	0.11822	0.906350
Pectoral skinfolds	7.2 ± 16.11	1.3 ± 18.56	1.25683	0.214430
Mid-axilla skinfolds	4.8 ± 9.27	-0.6 ± 13.48	1.73416	0.088815
Supraspinal skinfolds	8.1 ± 13.06	1.4 ± 11.71	1.99252	0.051575
Iliac crest skinfolds	0.1 ± 23.09	2.1 ± 15.49	-0.37193	0.711456
Abdominal skinfold	4.1 ± 13.87	6.6 ± 10.71	-0.73704	0.464412
Sum of 8 skinfolds[a]	1.5 ± 4.73	1.4 ± 4.55	0.39292	0.695983
GIRTHS				
Relaxed upper arm girth	3.8 ± 2.30 **	1.2 ± 2.70 **	3.7862 **	0.000398 **
Flexed upper arm girth	4.7 ± 2.16 **	2.1 ± 2.70 **	3.8114 **	0.000367 **
Corrected upper arm girth	4.7 ± 2.29 *	1.9 ± 2.89 *	3.99049 *	0.00208 *
Forearm girth	2.8 ± 2.30	2.0 ± 2.38	1.27916	0.206520
Wrist girth	0.0 ± 3.97	1.6 ± 3.29	-1.56837	0.122861
Half-chest girth	6.4 ± 3.19 **	2.8 ± 3.23 **	4.1047 **	0.000143 **
LENGTHS				
Upper arm length	-1.5 ± 6.49	0.2 ± 1.58	-1.32757	0.190120
Forearm length	0.9 ± 2.30	0.1 ± 2.38	1.23172	0.223595
Hand length	0.7 ± 1.84 *	-0.7 ± 2.10 *	2.59945 *	0.012124 *
Upper-limb length	-0.1 ± 2.71	0.0 ± 1.18	-0.18500	0.853947
BREADTHS				
Humerus	1.8 ± 2.73	2.9 ± 3.00	-1.37240	0.175830
Wrist	0.7 ± 5.81	-0.6 ± 4.62	0.91937	0.362146

[a] Sum of 8 skinfolds = biceps, triceps, subscapular, pectoral, mid-axilla, supraspinal, iliac crest, abdominal.

* $p < 0.05$

** $p < 0.001$

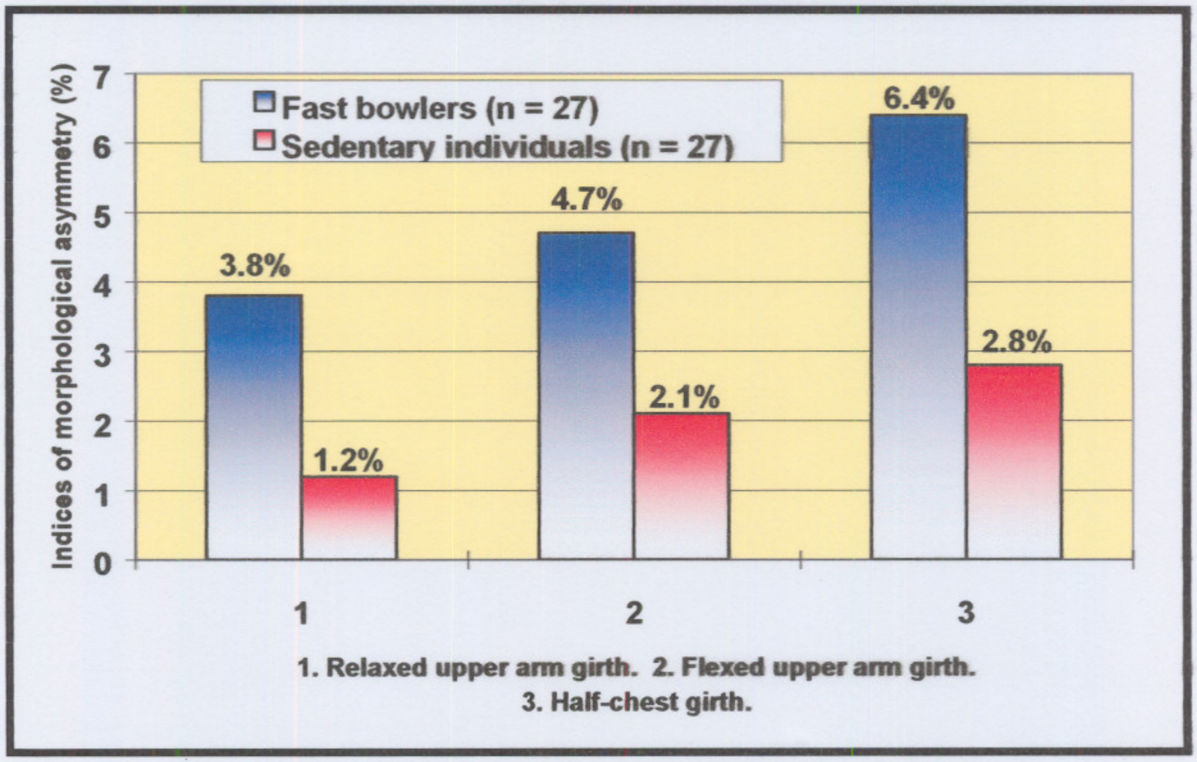

Figure 4: Graphs of the relative indices of morphological asymmetry of the fast bowlers (n = 27) and aged-matched sedentary individuals (n = 27) for the three variables which differed significantly ($p < 0.001$).

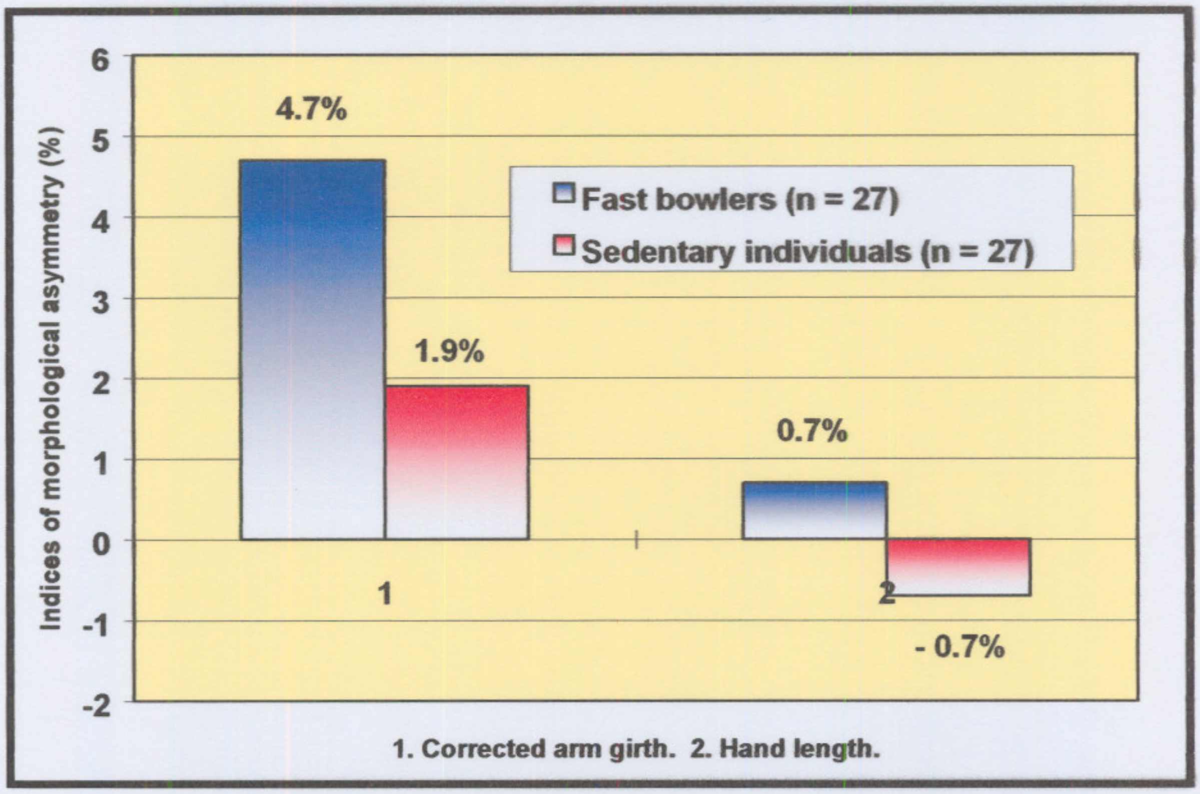

Figure 5: Graphs of the relative indices of morphological asymmetry of the fast bowlers (n = 27) and aged-matched sedentary individuals (n = 27) for the two variables which differed significantly ($p < 0.05$).

CONCLUSIONS

The following conclusions were drawn from the results of this study:

- The fast bowlers showed significant differences between the dominant and non-dominant side measurements for two upper body skinfold measurements (mid-axilla- and supraspinal skinfolds), five upper body girth measurements (relaxed upper arm, flexed upper arm, corrected upper arm, forearm and half-chest girths) and the humerus breadth measurement
- The fast bowlers showed no significant differences between the dominant and non-dominant side measurements for any upper body segment lengths
- No significant differences were found between the fast bowlers and the aged-matched sedentary individuals regarding indices of morphological asymmetry for any upper body skinfold and bone breadth measurements
- Significant differences were found between the fast bowlers and the aged-matched sedentary individuals regarding the indices of morphological asymmetry for four upper body girth measurements (the flexed upper arm, relaxed upper arm, corrected upper arm, and half-chest girths) and the hand length.

Even though morphological asymmetry was prevalent in both groups (fast bowlers and aged-matched sedentary individuals), the larger relative indices of morphological asymmetry in the group of fast bowlers could be attributed to the nature, intensity and frequency of the bowling action. The observed and measured morphological asymmetry in the sedentary individuals is the result of normal daily activities, in which the tendency is to make greater functional use of the dominant limb (Dangerfield, 1994; Margonato *et al.*, 1994). The fast bowlers are, however, also subjected to similar daily activities, thereby unequivocally indicating the additional effect of fast bowling on morphological asymmetrical development.

IMPLICATIONS

As the cross-sectional method of analysis was used to assess the asymmetrical morphological responses to fast bowling, it could not be established with certainty whether the observed morphological differences between the fast bowlers and sedentary individuals were the result of constitutional dissimilarities or the exclusive effects of fast bowling. It would, therefore, be of great value to conduct a longitudinal study on morphological asymmetry amongst cricket players (fast bowlers) and participants of other asymmetrical sport, to assess the structural and functional effects of intensive participation in such sport. The current study could be extended further, by including variables such as flexibility, strength, power, aerobic endurance and motor processes (for example, reaction time, speed of movement and co-ordination) in order to compile a complete profile of fast bowlers' and/or participants of other asymmetrical sport.

Starosta (1989) further developed a method called movement symmetrisation. Results of comprehensive studies on morphological asymmetry in different sport participants, could assist the Sport Scientist to develop such programmes specific to the needs of the sport, item or position and thereby contribute to the above mentioned movement symmetrisation programme. Groppel and Roetert (1992) also recommend the inclusion of flexibility, strength, power and endurance exercises for tennis players to limit injuries and asymmetrical development, whilst simultaneously enhancing the sporting performance. Information on the possible relationship between morphological asymmetry and certain injuries could be of further value. The effect of swimming programmes for the enhancement of symmetry or the prevention of the onset thereof, could be studied, as Coetzee (1994) indicated in his study on junior swimmers that swimming leads to symmetrical development. This study addressed a topic regarding this specific position in the sport, which up to now has been largely neglected.

The key to success in sport is to implement knowledge in a scientific manner and to continually research for new knowledge. For progression and performance in sport, all related aspects must be fully researched. The implementation of a complete spectrum of knowledge on asymmetry could possibly lead to a decrease in the number of injuries sustained by sportsman of all levels of participation, as well as enhance sporting performance, although these aspects need to be further researched.

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4 Morphological asymmetry amongst participants of asymmetrical (fast bowlers in cricket) and symmetrical (swimmers) sport and sedentary individuals in South Africa.

Mr. Heinrich W. Grobbelaar presented this article during the 2001 Southern African Congress in Sport Science in Stellenbosch. The abstract of this presentation was subsequently included in the Congress book of abstracts.

Grobbelaar, H.W.*, De Ridder, J.H. & Coetzee, B. 2001. Antropometriese verskille in die bolywe van deelnemers aan asimmetriese- (snelboulers in krieket) en simmetriese (kruipslagswemmers) sportsoorte en sedentêre persone in Suid Afrika. (Anthropometrical differences in the upper bodies of participants of asymmetrical- (fast bowlers in cricket) and symmetrical- (crawl-stroke swimmers) sports and sedentary individuals in South Africa.) (<u>In</u> Southern African Congress in Sport Science 2001 book of abstracts. Articles presented at the Southern African Congress in Sport Science held in Stellenbosch, South Africa on 5 – 9 November 2001. Stellenbosch. 60 p.)

This article will be presented for publication in the Journal of Sports Sciences. It is hereby included according to the specific guidelines of the journal, which is presented in Appendix B (Instructions for Authors).

Morphological asymmetry amongst participants of asymmetrical (fast bowlers in cricket) and symmetrical (swimmers) sport and sedentary individuals in South Africa.

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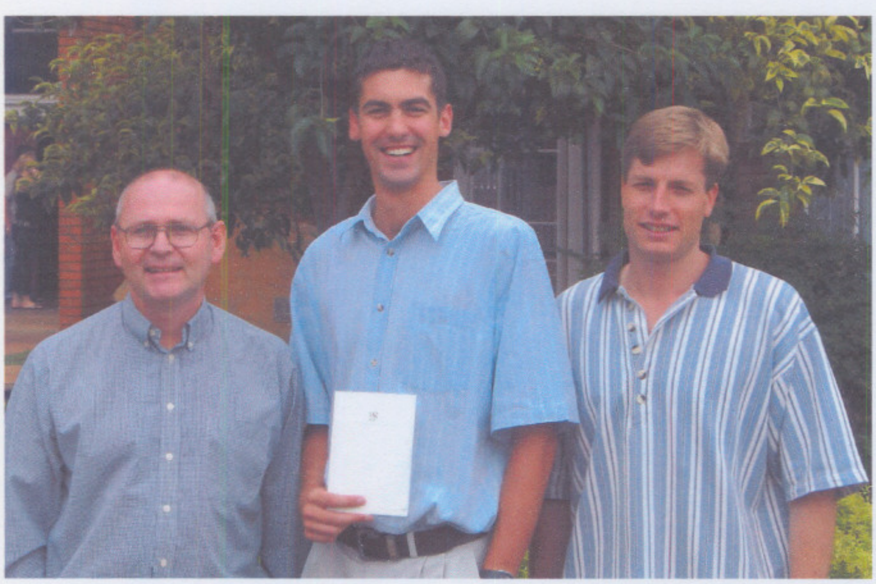

A photograph of Prof. Hans De Ridder, Mr. Heinrich Grobbelaar and Mr. Ben Coetzee, taken during the 2001 Southern African Congress in Sport Science, Stellenbosch, South Africa.

Morphological asymmetry amongst participants of asymmetrical (fast bowlers in cricket) and symmetrical (swimmers) sport and sedentary individuals in South Africa.

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The purpose of this study was firstly to determine whether significant differences exist between the dominant and non-dominant sides of male and female crawl stroke swimmers for thirty five anthropometrical measurements. Dependent *t*-tests revealed significant ($P<0.05$) differences for the upper arm girths, wrist girth, thigh girth and lower leg length amongst the males, whilst similar results were observed for the thigh girth, upper leg length and foot length amongst the females. The second purpose was to compare the relative indices of asymmetry (RIA) of male swimmers to that of male fast bowlers and aged-matched sedentary males for twenty upper body measurements. The RIA for these three groups are reported. An ANOVA with Tukey post hoc tests revealed significant ($P<0.05$) differences in the RIA of the upper arm girths and half-chest girth between the fast bowlers and the swimmers, as well as between the fast bowlers and the sedentary individuals. The RIA for the hand length differed significantly ($P<0.05$) between the fast bowlers and the sedentary individuals. All of the measured groups showed a certain degree of asymmetry for the different variables, with the fast bowlers portraying the highest and the swimmers the lowest RIA.

Keywords: Asymmetry, morphology, fast bowlers, cricket, crawl stroke swimmers, sedentary individuals.

Introduction

At the elite level of sport a strong relationship exists between human morphology and functioning (De Ridder *et al.*, 2000). Morphology (the science of structure and form without regard to function (Carter, 1985)) and the effect thereof on sporting performance has become a very important research topic. In this regard Stretch (1991), stated that morphology in itself is not the only criterion for optimum performance in sport, but that any deviations from the optimum standards could be a handicap to performance. One aspect of morphology that has not been thoroughly researched is that of asymmetry. Even though literature on morphological asymmetry does exist, Starosta (1989) indicates that many questions still need to be answered as to gain more knowledge of this subject.

More recently, studies on the topic were predominantly conducted on tennis players (Wyss *et al.*, 1989; Green *et al.*, 1996; Krawczyk *et al.*, 1998). These studies focused on the effects of unilateral activities on the physical and/or physiological attributes of the dominant limb, compared to the non-dominant limb. The significant differences of certain upper body morphological measurements between the two sides unequivocally indicate that unilateral activities have a significant effect on the nature of the asymmetrical development that occurs. Tennis is certainly not the only asymmetrical sport for which morphological asymmetries have been reported.

A photo of a high level fast bowler by Bloomfield *et al.* (1994) clearly demonstrates the type of asymmetrical upper body development that is commonly seen amongst fast bowlers. Stretch (1991) further reported lower limb asymmetry amongst a group of young fast bowlers, in that a number of these bowlers exhibited larger calf girths of the leg opposite to the bowling arm, when compared to the leg on the dominant side. Kippers *et al.* (1998) also found (in their study on provincial junior fast bowlers) that small indices of morphological asymmetry exist when the dominant and non-dominant limb measurements of the players were compared.

In contrast to these findings, Krawczyk *et al.* (1998) reported that participants of symmetrical sport, such as swimming, exhibit less asymmetrical deviations compared to those participating in asymmetrical sport types. Consistant with the data of Krawczyk *et al's* study (1998), previous research (Czabanski, 1974; Perrin, 1993; Coetzee, unpublished data) also reported very small indices of morphological asymmetry amongst swimmers. Despite the fact that most studies found a high degree of symmetrical development amongst swimmers, nearly half of the swimmers (49.9%) in Zaharieva's study (1981) showed asymmetry (of more than 0.3 cm) of the upper arm girths. The majority of findings, however, suggest that swimmers develop more symmetrically, due to the bilateral swimming technique that's used.

Several studies have also focused on the degree of asymmetrical development amongst sedentary individuals. Martorell *et al.* (1988), Dangerfield, (1994) and Margonato *et al.* (1994) all indicate that certain morphological variables do indeed show a degree of asymmetrical development amongst the sedentary population. According to Dangerfield (1994), this can be attributed mainly to side dominance and normal daily activities.

Apart from the rather high prevalence of morphological asymmetry amongst sport participants and sedentary individuals, the possible debilitative effect thereof on the health and performance of individuals (especially athletes) makes further research into this topic crucial. In this regard, Swärd (1992) has shown that a scoliosis frequency of more than 80% exists amongst participants of sports (such as javelin and tennis) in which movements occur where an asymmetrical load is placed on the trunk and shoulders. Although scoliosis is more likely to occur amongst participants of asymmetrical sports, Sallis (1994) indicated that scoliosis is quite common amongst younger swimmers and that such scoliosis may sometimes even be aggravated by swimming. Further evidence suggests that scoliosis is prevalent amongst 14.4% and 18.9% of the boys and girls from the sedentary population respectively (Willner, 1984). The possible prevalence of scoliosis is, therefore, one negative effect of morphological asymmetry.

It is in the light of this background and contradicting research findings that a study was undertaken to determine the prevalence of indices of morphological asymmetry amongst fast bowlers, swimmers and sedentary individuals. The purposes of this study are, therefore, firstly to determine whether (male and female) crawl stroke swimmers show significant differences between the dominant and non-dominant sides for selected anthropometrical measurements. The second purpose is to compare the indices of upper body morphological asymmetry between male fast bowlers, crawl stroke swimmers and sedentary individuals. The results of this study could be of great value to Sport Scientists, Physiotherapists and other role-players within the sporting fraternity, as it will focus these professionals' attention on the importance of specific preventive and therapeutical exercises for morphological asymmetry amongst sport participants.

Methods

This study firstly focuses on the indices of morphological asymmetry found amongst elite male and female crawl stroke swimmers. In addition to this, the indices of upper body morphological asymmetry of the male swimmers are compared to that of fast bowlers and sedentary individuals. Grobbelaar and De Ridder (2000) reported the data of the last two groups mentioned. This study is, therefore, a partial replication, but also a further extension of these previously published findings.

Subjects

Sixteen male swimmers (19.1±3.28 years) and eleven female swimmers (17.2±2.34 years), that reached one or more of the crawl event finals at the 2001 Telkom South African National Swimming Championships were measured during the championships.

Twenty seven high school fast bowlers (16.5±1.16 years) in a South African provincial cricket squad were measured. Other fast bowlers in this squad batting at numbers one to seven in the line-up were deliberately excluded from the measured group to limit the possible effect of batting on the different anthropometrical variables. The bowlers consisted out of 9 u/15, 8 u/17 and 10 u/19 players.

Eighty male high school pupils completed the Sport Participation Activity Profile Questionnaire (SPAPQ). The results of the SPAPQ were used to determine which of the pupils were sedentary. The results indicated that thirty five pupils were sedentary and had never participated in any asymmetrical sport types. Twenty seven subjects (16.1±0.87 years) were then randomly selected out of the group of thirty five. The sedentary group was included as a control group for this study.

Measurement procedures

All subjects were informed about the measurement procedures, possible risks and benefits of the research project. The subjects signed a written consent form before participation in the study. Demographic data and the sport participation history of the fast bowlers and swimmers were also gathered.

Thirty two anthropometric variables of the swimmers were measured on both sides of the body, according to the methods described by Norton *et al.* (1996). Two sets of measurements were taken for each variable, from which the mean was calculated and used for further analysis. Three more values were derived from this, bringing the total number to thirty five. A girth, namely the half-chest girth (as described by Grobbelaar and De Ridder, 2000) was also measured to determine the degree of asymmetry in the chest area. The half-chest girth is the horizontal distance from the midpoint of the sternum on the level of the mesosternal landmark to the spinous process of the vertebrae on the same level, taken at the end of a normal expiration.

The fast bowlers were measured prior to their training sessions at the facilities of the Cricket Union over a period of four weeks. The sedentary individuals were measured at their different schools. Only seventeen upper body measurements of each of the last two mentioned groups were taken, from which a further three values were derived.

Data analysis

The indices of morphological asymmetry of all the variables were calculated by using Wolafskis' Relative Indices of Asymmetry (RIA) (Copley, 1980) in which:

$$RIA = 2(X_D - X_{ND}) / (X_D + X_{ND}) \times 100$$

With X_D = variable on the dominant side
X_{ND} = variable on the non-dominant side
If RIA is +, then $X_D > X_{ND}$
If RIA is -, then $X_D < X_{ND}$.

In this equation, differences between the metrical traits of the dominant and non-dominant sides of the body are expressed as percentages of the sums of the dominant and non-dominant side traits. According to Copley (1980), this allows for the indices of asymmetry of different traits to be compared directly.

The Statistica Data Processing package (StatSoft Inc. 2000) was used to process the data. Dependent *t*-tests (between the dominant and non-dominant side measurements) were performed for each of the measured variables of the male and female swimmers. An ANOVA with Tukey post hoc tests were used for comparisons between the three male groups regarding the indices of morphological asymmetry in the upper body. Statistical significance was set at $P<0.05$.

Results and discussion

Table 1 shows the anthropometrical variables that differed significantly between the dominant and non-dominant sides of the male and female crawl stroke swimmers. Significant differences were observed in six of the variables of the males (relaxed arm, flexed arm, corrected arm girth, wrist girth, thigh girth (1cm gluteal) and lower leg length). Five of these measurements showed bigger values on the dominant side, whilst the lower leg length was longer on the non-dominant side. Only three measurements showed significant differences between the dominant and non-dominant lower extremities of females. The dominant thigh girth (1cm gluteal) and dominant thigh length were significantly larger than that of the non-dominant side, whilst the non-dominant foot length obtained a significantly bigger value than that of the dominant foot.

The results of the male swimmers' upper arm girths are in accordance with the findings of Zaharieva (1981), who indicated that 49.9% of the tested swimmers in a study showed asymmetries of greater than 0.3 cm for the upper arm girths. A plausible explanation for the finding that five of the dominant girths of the men's group and one of the women's group were significantly bigger compared to the non-dominant side, may lie in the research findings of Becker (1986) and Riewald and Lombardo (2002). These researchers report that swimmers exert a greater peak force with one arm and leg compared to the other during the kick phase or propulsion stroke of the swimming action. According to Riewald and Lombardo (2002) as well as Maglischo (2003), the asymmetrical stroke and kicking pattern may be the result of the unilateral breathing techniques commonly used by crawl stroke swimmers. The causes of the differences in the lower leg lengths (of the males) and upper leg lengths (of the females) are presently unknown, however, a possible reason emerged in the literature. Kemper (2000) indicated that bone structures are dynamic tissue, which adapt to loading exerted on it. This argument is also supported by Grimston *et al.* (1993) who indicated that mechanical loading could change and/or stimulate the growth patterns of a certain bone structure. It is, therefore possible that swimmers exert more force with the one leg compared to the other during tumble turns, and that this may over time lead to the anthropometrical discrepancies that were found. The phenomenon that the women's dominant foot length was significantly smaller than that of the non-

Table 1 Average anthropometrical values, indices of asymmetry as well as significance of differences between the dominant and non-dominant sides of crawl stroke swimmers.

Variables	Descriptive statistics			Significance (P)
	Dominant side (cm)	Non-dominant side (cm)	Indices of asymmetry	
Male swimmers (n=16)				
Relaxed upper arm girth	31.0±2.46	30.5±2.28	1.5±2.45%	0.020574
Flexed upper arm girth	33.2±2.43	32.8±2.44	1.0±1.30%	0.010264
Corrected upper arm girth	32.3±2.41	32.0±2.43	0.8±1.41%	0.037363
Wrist girth	17.3±0.82	16.9±0.91	2.2±2.12%	0.000764
Thigh girth (1 cm gluteal)	55.9±3.82	55.3±3.90	1.1±2.00%	0.046872
Lower leg length	40.5±1.94	41.0±1.99	-1.2±1.90%	0.018197
Female swimmers (n=11)				
Thigh girth (1cm gluteal)	56.7±3.04	55.9±2.97	1.4±1.14%	0.001704
Upper leg length	44.3±1.96	43.4±1.52	2.0±2.78%	0.041861
Foot length	24.7±1.05	25.0±0.91	-1.3±1.79%	0.041762

dominant side can, however, not be explained.

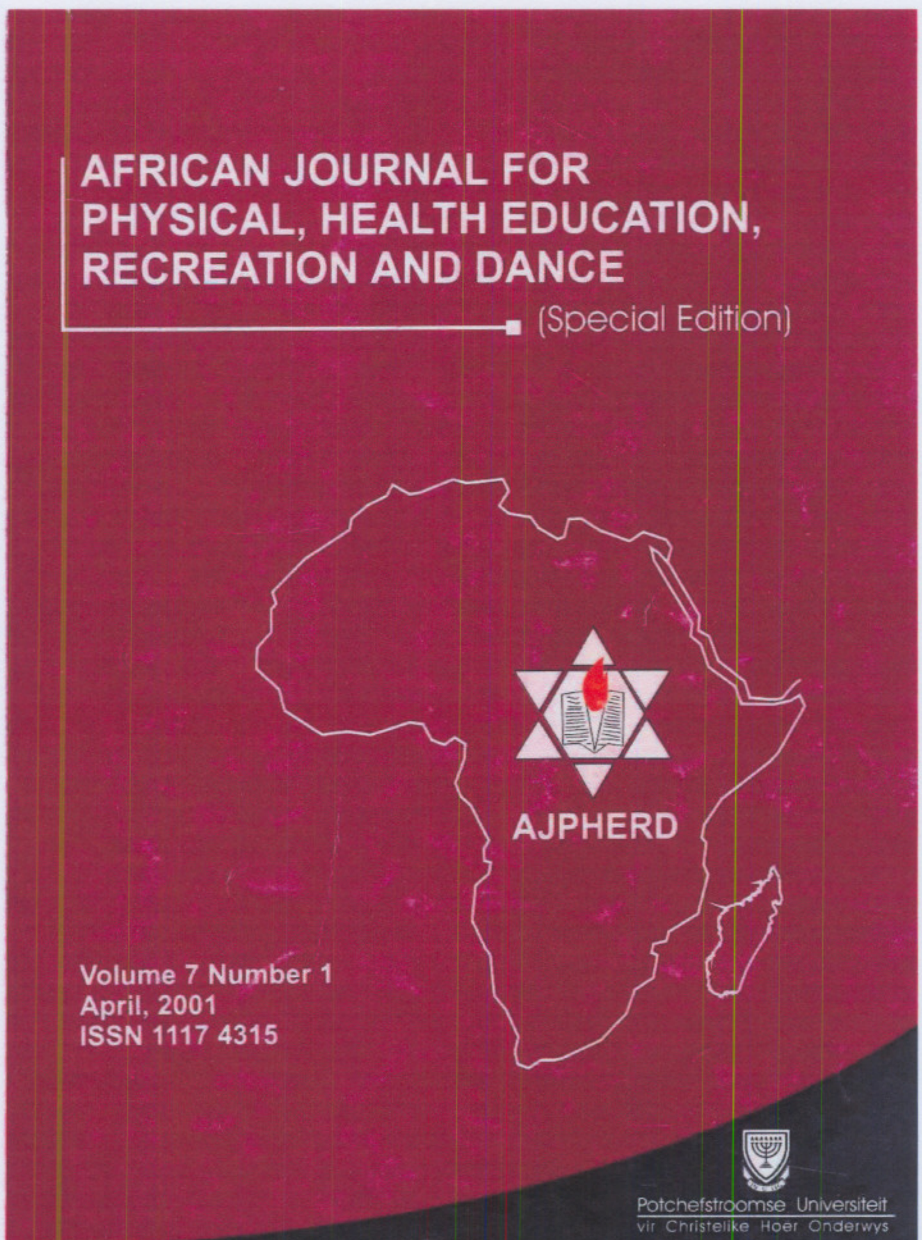
The descriptive statistics as well as results of the *t*- and post hoc tests with regard to the indices of morphological asymmetry of the male fast bowlers, crawl stroke swimmers and sedentary individuals are presented in Table 2 and Figure 1. The results of the subject group with the lowest indices of morphological asymmetry for each of the measured variables are highlighted in Table 2. With regard to the ANOVA results, it should be noted that no studies exist in which the indices of asymmetry differences between different sporting populations have been conducted.

As shown in Table 2, the male swimmers achieved the smallest RIA values for the majority (8 out of 11) of the girth, length and breadth measurements. In contrast to these results, the fast bowlers obtained the greatest RIA values for most (9 out of 11) of their girth, length and breadth measurements. The skinfold data does not show a fixed trend across the different subject groups. This fact was further substantiated by the results of the simple analysis of variance, which showed that no significant differences between the three groups exist for the skinfold measurements. The same applied for some of the girths (forearm and wrist), lengths (upper arm, forearm and upper limb) and the humerus breadth. The relaxed, flexed and corrected upper arm, as well as the half-chest girths, however, differed significantly with regard to the indices of morphological asymmetry between the fast bowlers and the swimmers and the fast bowlers and the sedentary individuals, respectively. The RIA for the hand length differed significantly between the fast bowlers and the sedentary individuals only.

The results of the simple analysis of variance concerning the fast bowlers are not strange. The relatively large RIA of the upper arm and half-chest girths of the fast bowlers is indicative of athletes who participate in unilateral sport in which elbow flexion and extension (upper arm muscles) as well as shoulder

Appendix A.

Guidelines for contributors: African Journal for Physical, Health Education, Recreation and Dance



Appendix B.

Instructions for authors: Journal of Sports Sciences

athletes who show a high degree of morphological asymmetry due to participation in unilateral sport types.

Additional research is needed to determine the effect of a short and long term swimming programme on the morphological make-up of athletes participating in asymmetrical sport. Such longitudinal studies must not only be limited to the morphological composition of athletes, but must also give attention to the flexibility and strength asymmetry that may exist. Further research is also necessary to investigate the factors that may contribute to such morphological and physiological asymmetries.

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5 Summary, conclusions and recommendations.

5.1 SUMMARY

The purpose of this study was firstly to determine whether fast bowlers, crawl stroke swimmers and aged-matched sedentary individuals showed significant differences between the dominant and non-dominant sides for certain anthropometric measurements. The second purpose was to compare the fast bowlers, crawl stroke swimmers and aged-matched sedentary individuals with regard to the indices of upper body morphological asymmetry. Chapter 1 provided a brief outline of the problem statement that underlies the research questions as well as the research questions, purposes and hypotheses that forms the basis of this study.

Chapter 2 is a literature review of the nature and prevalence of morphological asymmetry amongst sport participants and sedentary individuals. The chapter firstly introduced the reader to the literature format of this chapter by means of an introduction. The introduction is followed by a section that deals with the definitions and terminology pertaining to asymmetry, as well as the criteria used to determine side dominance and the methods for calculating asymmetry. This is followed by a literature review of the prevalence of morphological asymmetry amongst participants of unilateral and bilateral sports as well as sedentary individuals. The last section of the chapter deals with the causes and negative effects of morphological asymmetry. The chapter was concluded by focusing on the possible preventive and therapeutic measures that can be used to reduce and remedy the occurrence of asymmetry amongst athletes.

This dissertation is submitted in article format, as approved by the Senate of the PU for CHE and, therefore, includes two articles (in Chapters 3 and 4 respectively), of which one has already been published. The first article entitled "Asymmetry in the upper body of high school fast bowlers in cricket in South Africa", has been published by Grobbelaar, H.W. and De Ridder, J.H. in the African Journal for Physical, Health Education, Recreation and Dance, 2001:7(1):61-76. It is included in this dissertation with the consent of the Journal's editor. The main purposes of this article were firstly to determine whether morphological asymmetry is found in the upper body of fast bowlers, and secondly, to determine if fast bowlers show significantly greater indices of morphological asymmetry than aged-matched sedentary individuals.

The second article entitled "Morphological asymmetry amongst participants of asymmetrical (fast bowlers in cricket) and symmetrical (swimmers) sports and sedentary individuals in South Africa", by Grobbelaar, H.W., De Ridder, J.H. and Coetzee, B. will be presented for publication in the Journal of Sports Sciences. This article is included as Chapter 4. The first purpose of this study was to determine the morphological differences between the dominant and non-dominant sides of elite male and female crawl stroke swimmers for thirty five anthropometrical measurements. The second purpose was to compare the indices of asymmetry for twenty upper body measurements for male fast bowlers, crawl stroke swimmers and sedentary individuals. This article is a partial replication, but also a further extension of the previously published findings by Grobbelaar and De Ridder (2000).

Both articles are included according to the guidelines of the specific journals and consist of an introduction, problem statement and the resulting research questions and purposes of the study. The research methods (subjects, measurement procedures and data analysis) are described, after which the results are presented and discussed. Each article concludes with research conclusions and implications.

5.2 CONCLUSIONS

The conclusions that are drawn from this research are presented in accordance with the set hypotheses (Chapter 1).

5.2.1 Hypothesis 1: *Fast bowlers will show significant differences between the dominant and non-dominant side measurements for selected anthropometrical variables.*

Hypothesis 1 is accepted based on the research findings that statistically significant differences were found for eight of the twenty one anthropometrical variables amongst the group of fast bowlers, when the dominant and non-dominant side measurements were compared. The girth measurements showed the biggest differences in the comparison of the dominant and non-dominant sides.

5.2.2 Hypothesis 2: ***Crawl stroke swimmers and sedentary individuals will show small, but significant differences between the dominant and non-dominant side measurements for selected anthropometrical variables.***

Hypothesis 2 is accepted for both the male and female crawl stroke swimmers based on the research findings that statistically significant differences were found for six and three of the thirty five anthropometrical variables respectively, when the dominant and non-dominant side measurements were compared. The girth measurements showed the biggest differences in the comparison of the dominant and non-dominant sides.

Hypothesis 2 is accepted for the group of sedentary male individuals, based on the research findings in which statistically significant differences were found for nine of the twenty one upper body anthropometrical variables, when the dominant and non-dominant side measurements were compared. The girth measurements showed the biggest differences in the comparison of the dominant and non-dominant sides.

5.2.3 Hypothesis 3: ***Fast bowlers will show significantly greater indices of morphological asymmetry for selected upper body anthropometrical variables than the crawl stroke swimmers and sedentary individuals.***

Hypothesis 3 is accepted based on the research findings that significantly greater indices of morphological asymmetry were found for four of the twenty anthropometric variables amongst the group of fast bowlers, when compared to the crawl stroke swimmers and sedentary males respectively. These four variables are all girth measurements, whilst the indices of asymmetry for the hand length of the fast bowlers and the sedentary male individuals also differed statistically significantly. No statistically significant differences were found between the crawl stroke swimmers and the sedentary male individuals. It is of further importance to note that the crawl stroke swimmers were the most symmetrical group, as they reported the lowest indices of morphological asymmetry (of the three male groups) for thirteen of the twenty measured variables. The fast bowlers showed the greatest indices of morphological asymmetry (of the three male groups) for twelve of the twenty measured variables and can, therefore, be regarded as the most asymmetrical group.

5.3 RECOMMENDATIONS

The results from this study emphasise the importance of further research regarding the indices of asymmetry amongst participants of various sports, as there is clearly a shortage of literature that focuses on this research theme. Future studies should not only be limited to morphological asymmetry, but also give attention to flexibility and strength development asymmetry to give more insight into this research field. The possible causative factors of asymmetry should also be investigated, in order to compile preventative measures to limit the onset and development of these asymmetries. The debate concerning the possible negative effects of morphological asymmetry on the health and performances of athletes vindicate more in depth research into this relationship.

The findings of this study give rise to the argument that swimming might be a good exercise for the prevention of asymmetrical morphological development, as well as the exercise of choice in cases where morphological asymmetries are prevalent, such as amongst participants of various asymmetrical sports. The need for more research to investigate the specific influence of swimming programmes on the morphological asymmetry of elite fast bowlers and other participants of unilateral sport, can, therefore not be over emphasised.

Certain shortcomings regarding this study, can, however, be indicated:

- A cross-sectional method of analysis was used to assess the asymmetrical morphological responses of athletes and sedentary individuals to sport and/or normal daily activities. It could, therefore, not be said with certainty that the observed differences between the different groups were the result of constitutional dissimilarities or the effects of normal daily and/or sport activities. A longitudinal study that focuses on the influence of certain daily and sport activities on the onset and development of morphological asymmetry would be a more suited approach to research this aspect.

- A small number of subjects was included in each of the four groups in this study. Outliers, therefore, had a much greater influence on the total group results than would have been the case with a larger sample size. Further research of this nature must, therefore focus on larger subject groups.

- For studies such as the present one, in which comparisons between different groups of athletes are made, the ideal is that athletes from the same competitive level should be used. The fact that the swimmers participated on a national level and the fast bowlers on a provincial level, could have caused certain discrepancies.

5.4 REFERENCES

GROBBELAAR, H.W. & DE RIDDER, J.H. 2000. Asymmetry in the upper body of High School fast bowlers in cricket in South Africa. *African Journal for Physical, Health Education, Recreation and Dance*, 7(1):61-76, Apr.

Appendix A.

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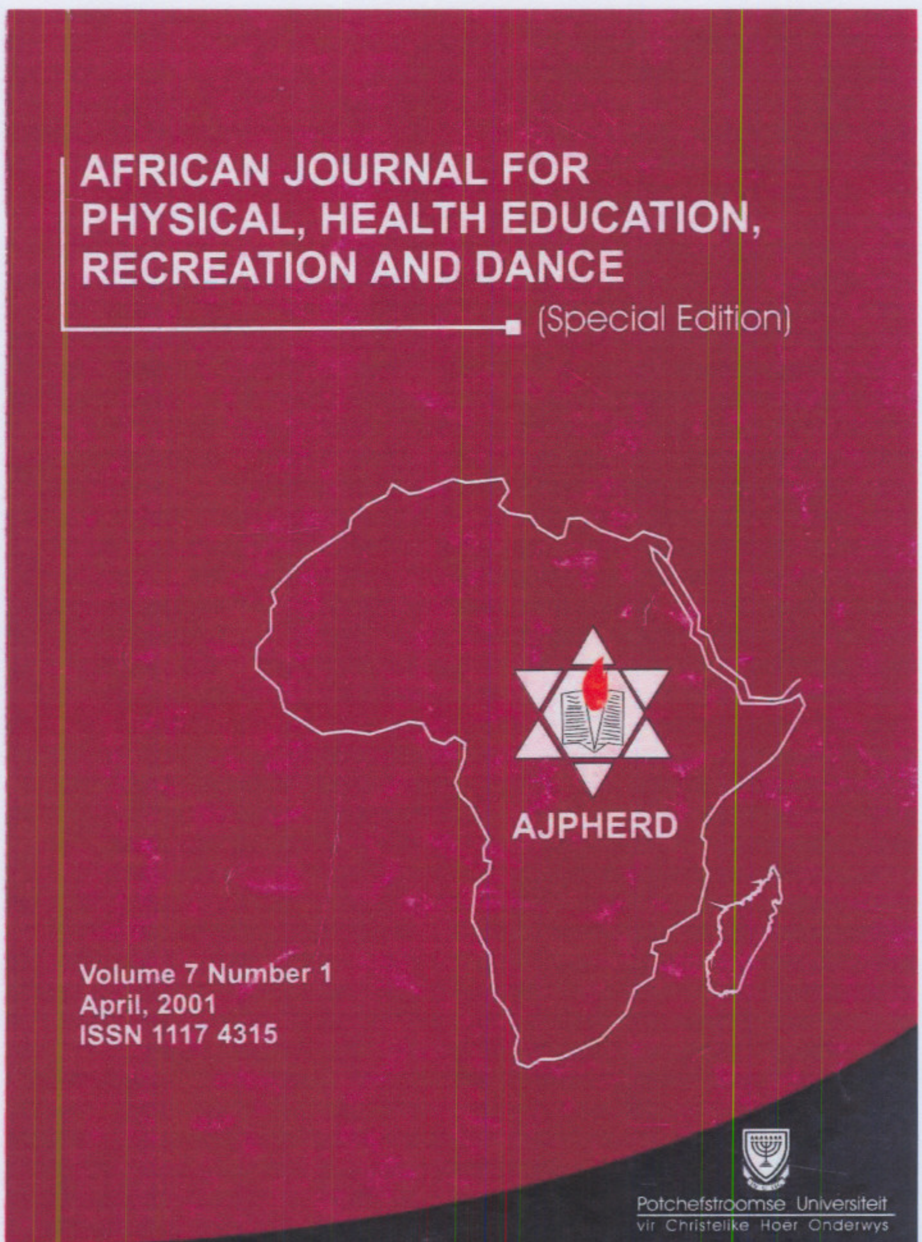

AFRICAN JOURNAL FOR PHYSICAL, HEALTH EDUCATION, RECREATION AND DANCE

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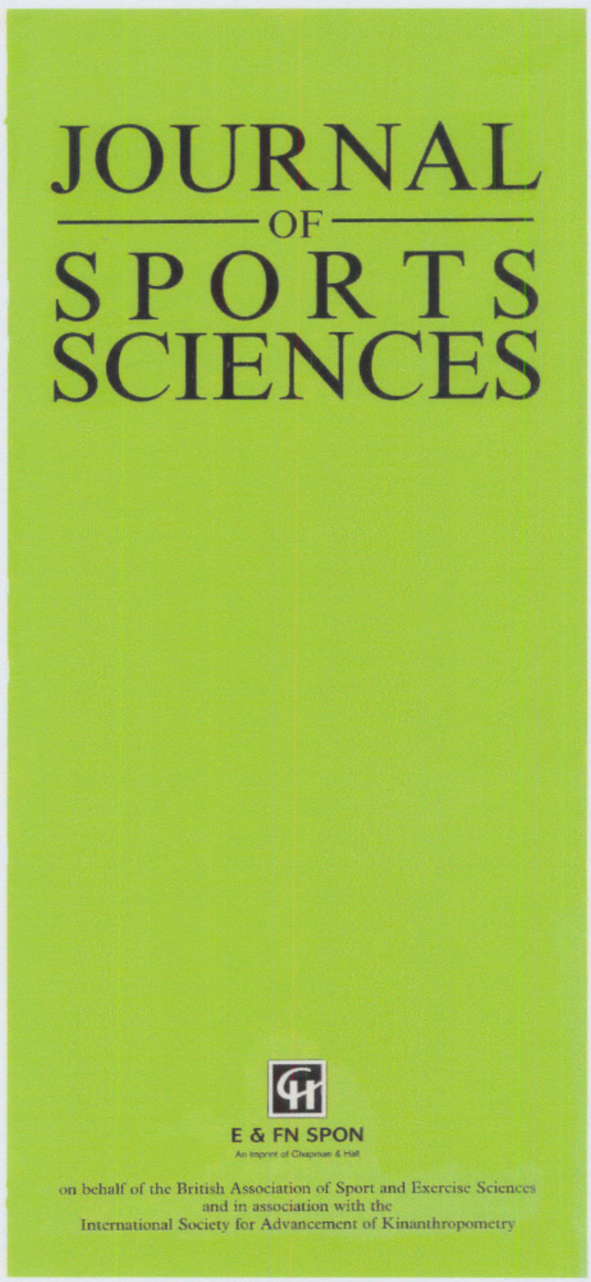

JOURNAL OF SPORTS SCIENCES

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