Acute effects of three recovery techniques on certain physical, motor performance and haematological components in university-level rugby players

A Broodryk

21673144

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

It all starts here ™

Acute effects of three recovery techniques on certain physical, motor performance and haematological components in university-level rugby players

A Broodryk

21673144

Supervisor: Dr C Pienaar

Co-Supervisor: Ms M Sparks

Assistant Supervisor: Prof B Coetzee

November 2014

FOREWORD

I dedicate this dissertation to my Heavenly Father, my Savior, and my King. Words cannot describe the love I have for You. Thank you for all my talents that You blessed me with and the opportunity to use it in glorifying Your name. Thank You for Your unconditional love.

I would like to take this opportunity to express my sincere appreciation to the following special people for their assistance, guidance and support during the last couple of years:

Aan my ouers, Moekie en Toy, baie dankie vir al julle opofferinge deur al die jare en dat julle dit moontlik gemaak het vir my om te studeer en gedeel het in al my drome. Moekie, dankie vir Ma se ondersteuning in alles wat ek aanpak, hetsy op die sportveld, die verhoog of my studies. Toy, dankie vir al die motivering rondom die voltooiing van hierdie graad. Dankie vir julle liefde.

My twee ongelooflike sussies, Anya en Amei. Ons het al ŉ paar harde klippe saam gekou maar julle het vir my deur die jare bewys wat is onvoorwaardelike liefde. Dankie vir die spesiale band wat ons het, ek kan nie my lewe voorstel sonder julle nie. Ons sal altyd die A-span bly.

To all my study leaders, Cindy, Martinique and Ben. Thank you for all your guidance, your hard work and support. You are truly an inspiration and I continue to learn from you on a daily basis.

Lastly, my loving husband, Retief. Thank you so much for all your love, support and encouragement in everything I do. You always see the best in me and push me to go beyond my boundaries. You are truly my best friend and soul mate. I love you with all my heart.

> *"I press on toward the goal to win the prize for which God has called me heavenward in Christ Jesus, as I can do everything through Him who strengthens me." - Philippians 3:14; 4:13*

DECLARATION

The co-authors of the two articles (Ethical number: NWU-00201-14-A1), which form part of this dissertation, Doctor Cindy Pienaar (Supervisor), Ms. Martinique Sparks (Co-supervisor) and Professor Ben Coetzee (Assistant-supervisor) hereby give permission to the candidate Mss. Adéle Broodryk to include the two articles as part of a Masters dissertation. The contribution (advisory and supportive) of the co-authors was kept within reasonable limits, thereby enabling the candidate to submit this dissertation for examination purposes. This dissertation, therefore, serves as a partial fulfillment of the requirements for the Magister Arts degree in Sport Science within the School of Biokinetics, Recreation and Sport Science in the Faculty of Health Sciences at the North-West University (Potchefstroom campus), South-Africa.

Dr. Cindy Pienaar

Supervisor and co-author

Sparks

Ms. Martinique Sparks

Co-supervisor and co-author

Prof. Ben Coetzee

Assistant-supervisor and co-author

SUMMARY

Acute effects of three recovery techniques on certain physical, motor performance and haematological components in university-level rugby players.

Rugby has become a popular team sport worldwide with players training harder and competing more frequently, placing a great physiological demand on their bodies. To retain this performance level, players need to recover sufficiently between training and competitions. Two popular recovery techniques used are cold water immersion (CWI) and contrast water therapy (CWT). Despite numerous publications a lack still exists with regard to these specific recovery methods on physical and haematological parameters. Against this background, the main objectives of this study were firstly, to determine the effects of CWI compared to those of passive recovery (PAR) over a 48-hour period on physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players. Secondly, to determine the effects of CWT compared to those of PAR over a 48-hour period on physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players.

Twenty-three rugby players of the North-West University participated in the study. The players were randomly assigned to either a control (*n* = 11; age: 20.1±0.3 y) or experimental (*n* = 12; age: 19.9±0.3 y) group. Participants reported to the laboratory where base line measurements were taken on certain physical (vertical jump test (VJT) height, VJT peak speed, VJT peak power and grip strength) and haematological (base excess (BEx), blood lactate (BLa^-), calcium (Ca^+), bicarbonate (HCO_3), haemoglobin, haematocrit, pH level, partial oxygen level (PO_2), partial carbon dioxide (PCO_2), plasma glucose, potassium (K^+), saturated oxygen (SO_2), sodium (Na^+) and total carbon dioxide (TCO_2)) components. Thereafter participants were accompanied to the field to complete an intense anaerobic exercise session, followed by a recovery period of either CWI *vs.* PAR (week 1) or CWT *vs.* PAR (week 2). The recovery session comprised of either sitting passively in a still area (PAR), or immersion of CWI (8–10°C), or alternating immersions of five cycles between cold (1 min; 8–10°C) and warm water (3min; 40-42°C), totalling 20 minutes. Exactly three minutes, 24 and 48 hours after the recovery intervention all the measurements were re-taken to assess acute and longer-term effects of recovery. Descriptive statistics were followed by a linear mixed model analysis with an autoregressive 1 heterogeneous (AR1-Heterogeneous) structure, and between-group differences were examined using a one-way analysis of variance (ANOVA). Significance was set at $p \leq 0.05$. Effect sizes were calculated to determine practical significance per recovery intervention as well as within groups.

CWI indicated better recovery than PAR, with three out of the nine variables (BLa^-, Na^+ and haemoglobin) returning at 0 h post-recovery, and five (PO_2, plasma glucose, VJT height, VJT peak power, VJT peak speed) only at 24 h post-CWI. In contrast, the PAR-group did not demonstrate recovery in any of the variables at 0 h post-PAR. However, an improvement was seen in VJT height across all time points. Four (BLa^-, haemoglobin, VJT peak power and VJT peak speed) out of a possible nine variables recovered at 24 h with an additional two (PO_2 and grip strength) variables showing recuperation at 48 h. A significant decrease ($p \leq 0.05$) was seen in VJT height, PO_2 and Na^+ from post-anaerobic to immediately following either CWI or PAR (except for VJT height). Significant increases ($p \leq 0.05$) were observed in VJT height, plasma glucose, and Na^+ from 0 h post-recovery to 48 h post-recovery for both CWI and PAR. PO_2 also significantly increased ($p \leq 0.05$) from 0 h to 24 and 48 h post-CWI and for the PAR-group at 48 h. CWI tended to have a faster recovery rate than PAR over a 24-h period.

The CWT vs. PAR showed the same trend, at 0-hours, six variables (BLa^-, haemoglobin, VJT-height, VJT peak-power, VJT peak-speed and grip strength) was restored to base line, whereas plasma glucose recovered at 24-hours post-CWT. In addition, players' jump and grip strength performance improved from base line. The PAR-group demonstrated recovery at 0 hours in four variables (BLa^-, VJT height, VJT peak-speed and grip strength), and two variables (Na^+ and haemoglobin) at 24-hours and plasma glucose at 48 hours. A significant decrease ($p \leq 0.05$) was seen in haemoglobin and BLa^- from post-anaerobic to either 24 or 48 hours for both groups. A significant increase in plasma glucose and PO_2 from 0 to 24 hours was observed in both groups. No significant intergroup change in physical components was noticed. However, intergroup results indicated CWT to be superior to PAR with statistical significance observed in BLa^- and grip strength ($p \leq 0.05$) at various time points.

The conclusion drawn from the above-mentioned results is that a recovery session comprising either 20-minutes of CWI or CWT may lead to significantly better physical components and restoration of haematological components in university-level rugby players compared to that of passive recovery. However, a detrimental effect was noticed in some components over the recovery period.

Keywords: cold water immersion, contrast water therapy, rugby, physical, haematological

OPSOMMING

Die akute effek van drie herstel tegnieke op sekere fisieke, motoriese en hematologiese komponente in universiteit vlak rugby spelers.

Rugby het wêreldwyd ŉ gewilde spansport geword met spelers wat harder oefen en meer dikwels kompeteer, wat ŉ hoër fisiologiese eis aan hul liggame stel. Om vol te hou met hierdie vlak van deelname moet spelers voldoende herstel tussen oefening en kompetisies. Twee gewilde herstel tegnieke wat gebruik word, is kouewater-onderdompeling (KWO) en kontras water-terapie (KWT). Ten spyte van talle publikasies bestaan daar steeds ŉ gebrek aan navorsing oor die spesifieke herstel metodes rakende verskeie fisiese en hematologiese veranderlikes. Teen hierdie agtergrond was die hoofdoelstellings van hierdie studie eerstens om die effekte te bepaal van KWO vergeleke met dié van passiewe herstel (PAH) op die fisiese en hematologiese parameters na ŉ intense anaerobiese oefensessie oor ’n periode van 48 uur heen van ŉ kohort manlike universiteitsvlak rugbyspelers. Tweedens, om die effekte van KWT vergeleke met dié van PAH op die fisiese en hematologiese parameters na ’n intense anaerobiese oefensessie oor ŉ 48-uur periode heen van ’n kohort manlike universiteitsvlak rugbyspelers.

Drie en twintig rugbyspelers vanuit die Noord-Wes universiteit het aan die studie deelgeneem. Die spelers is lukraak óf aan ŉ kontrole- (*n* = 11; ouderdom: 20.1±0.3 jaar) óf eksperimentele groep (*n* = 12; ouderdom: 19.9±0.3 jaar) verdeel. Deelnemers het by die laboratorium aangemeld waar basislynmetings op bepaalde fisiese (vertikalesprong-toets (VST) hoogte, VST-piekkrag, VST-piekspoed en greepkrap) en hematologiese (basis oortollig (BEx), bloedlaktaat (BLa^-), kalsium (Ca^+), bikarbonaat (HCO_3), hemoglobin, hematokrit, parsiële suurstofvlak (PO_2), parsiële koolstofdioksied vlak (PCO_2), plasma glukose, kalium (K^+), versadigde suurstofvlak (SO_2), natrium (Na^+) en totale koolstofdioksied(TCO_2)) komponente geneem is. Daarna is deelnemers na die veld vergesel om ŉ intense anaerobiese oefensessie te voltooi, opgevolg deur ŉ hersteltegniek van óf KWI vs. PAH (week 1) óf KWT vs. PAH (week 2). Die herstel sessie het bestaan of passiewe sit in ŉ stil area, of KWO (8–10°C) of die alternering van vyf siklusse tussen koue water (1 min; 8–10°C) en warm water (3min; 40-42°C) onderdompeling vir ŉ totale periode van 20 minute. Presies drie minute, 24 en 48 uur na herstel-intervensie is al die metings weereens geneem om akute en langtermyn-effekte van herstel te assesseer. Beskrywende statistiek is deur ŉ lineêre gemengdemodel-analise met ŉ outoregressiewe 1 heterogene

(OR1-Heterogene) struktuur, en tussengroep-verskille is ondersoek aan die hand van ŉ eenrigtingvariansieanalise (ANOVA). Betekenisvolheid is op $p \leq 0.05$ gestel. Effekgroottes is bereken om praktiese betekenisvolheid per herstel-intervensie asook in groepe te bepaal.

KWO het ŉ vinniger herstel getoon, met drie uit die nege veranderlikes (BLa^-, Na^+ en hemoglobien) by 0 uur post-herstel en vyf (PO_2, plasma glukose, VST-hoogte, VST-piekkrag, VST-piekspoed) by 24 uur post-KWO. Hierteenoor het die PAH-groep nie herstel in enige van die veranderlikes onmiddellik na PAH getoon nie. ŉ Verbetering is egter waargeneem in VST-hoogte oor alle tydpunte heen. Vier (BLa^-, hemoglobien, VST-piekkrag en VST-piekspoed) uit ŉ moontlike nege veranderlikes het by 24 uur herstel, met ŉ bykomstige twee (PO_2 en greepkrag) veranderlikes wat by 48 uur herstel getoon het. ŉ Betekenisvolle afname ($p \leq 0.05$) is in VST-hoogte, PO_2 en Na^+ waargeneem van post-anaerobiese tot onmiddellik na óf KWO óf PAH (met die uitsondering van VST-hoogte). Betekenisvolle toenames ($p \leq 0.05$) is in VST-hoogte, plasma glukose en Na^+ van 0 uur post-herstel na 48 uur post-herstel vir beide KWO en PAH waargeneem. PO_2 het ook betekenisvol toegeneem ($p \leq 0.05$) van 0 uur tot 24 en 48 uur post-KWO en vir die PAH-groep by 48 uur.
KWO was geneig om ŉ vinniger hersteltempo as PAH oor ŉ 24-uur periode heen te hê.

Die KWT vs. PAH het dieselfde neiging getoon, met ses veranderlikes (BLa^-, hemoglobien, VST-hoogte, VST-piekkrag, VST-piekspoed en greepkrag) wat by onmiddelik na herstel digby basislyn herstel het, terwyl plasma glukose by 24 uur post-KWT herstel het. Hierbenewens het spelers se VST- en greepkrag-prestasie van basislyn af verbeter. Die PAH-groep het herstel getoon in vier veranderlikes (BLa^-, VST-hoogte, VST- piekspoed en greepkrag) by 0 uur en twee veranderlikes (Na^+ en hemoglobien) by 24 uur asook plasma glukose by 48 uur. Verder is ŉ betekenisvolle afname ($p \leq 0.05$) in hemoglobien en BLa^- van post-anaërobies tot óf 24 of 48 uur vir beide groepe waargeneem. ŉ Betekenisvolle toename in plasma glukose en PO_2 van 0 tot 24 uur is in beide groepe waargeneem. Geen betekenisvolle intergroep-verandering in enige fisiese komponente was waargeneem nie. Intergroep-resultate het egter aangetoon dat KWT superior is tot PAH met betekenisvolheid wat in BLa^- en greepkrag ($p \leq 0.05$) by verskeie tydpunte waargeneem is.

Die gevolgtrekking vanuit bogenoemde resultate, is dat ŉ herstel-sessie wat uit óf 20 minute se KWO óf KWT bestaan, tot betekenisvol beter fisiese komponente en herstel van hematologiese komponente by universiteitsvlak rugbyspelers vergeleke met die van passiewe herstel kan lei. ŉ Nadelige effek is egter in sommige komponente oor die herstelperiode heen opgemerk.

Sleutelwoorde: kouewater-onderdompeling, kontras water-terapie, rugby, fisiese, hematologiese

TABLE OF CONTENTS

CHAPTER 1

CHAPTER 2

CHAPTER 3

LIST OF TABLES

CHAPTER 2:

CHAPTER 3:

CHAPTER 4:

LIST OF FIGURES

CHAPTER 2:

CHAPTER 3:

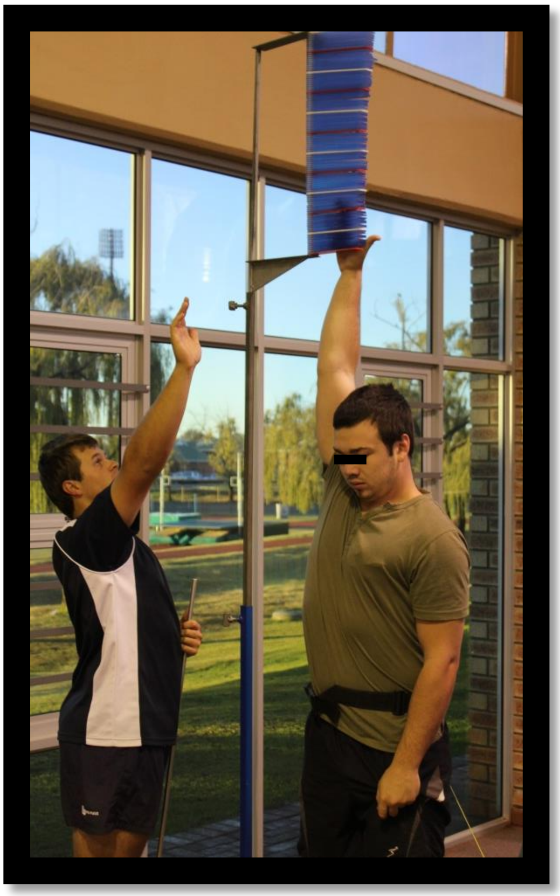
CHAPTER 4:

LIST OF ABBREVIATIONS

µL	Micro Liter
BLa^-	Blood Lactate
CK	Creatine Kinase
cm	Centimeter
CMJ	Countermovement Jump
CWI	Cold Water Immersion
CWT	Contrast Water Therapy
d	Practical Significance
DOMS	Delayed Onset Muscle Soreness
F	Ratio of variance between groups
h	Hours
HCO_3	Bicarbonate
HR	Heart Rate
K^+	Potassium
kg	Kilograms
m	Meters
$m.s^{-1}$	Meters per second
min	Minutes
mm	Millimeters
mmol/L	Millimoles per liter
MVC	Maximal Voluntary Contraction

n	Number of subjects in each subgroup
Na^+	Sodium
ºC	Degrees Celsius
O_2	Oxygen
p	Statistical Significance
PAR	Passive Recovery
PCO_2	Partial Carbon dioxide
PMS	Perceived Muscle Soreness
PO_2	Partial Oxygen
Post-An.	Post-Anaerobic
Post-Rec.	Post-Recovery
Pre-An.	Pre-Anaerobic
PSO_2	Partial Saturated Oxygen
r	Correlation
Rec	Recovery
RPE	Rate of Perceived Exertion
RSA	Repeated Sprint Ability
SD	Standard Deviation
sec	Seconds
VJT	Vertical Jump Test
VO_2	Oxygen Uptake
VO_2 peak	Peak Oxygen Uptake
W	Watts

CHAPTER 1



1

INTRODUCTION

1. INTRODUCTION
2. PROBLEM STATEMENT
3. OBJECTIVES
4. HYPOTHESIS
5. STRUCTURE OF DISSERTATION
6. REFERENCES

1. INTRODUCTION

Rugby union is a popular team sport played worldwide (Brooks *et al.*, 2005:757) with an 80-minute match consisting of various intensity-level activities (such as speed, agility, power, endurance, flexibility, sport-specific skills (Duthie *et al.*, 2003:983), aerobic- and anaerobic periods and direct impact between players (Gill *et al.*, 2006:260)). The two major positional groups (forward and backline players) demonstrate different exercise and performance roles, with the forward players averaging around 13.9% of the total match time in intense static activity (rucking, mauling and scrummaging), and the backline players averaging only 1.3% of the total time in these activities (Deutsch *et al.*,1998:569). During a match the players are subjected to various performance indicators such as scrummaging, rucking, mauling, lineouts and tackles (Duthie *et al.*, 2003:984). This emphasizes the importance of achieving the right balance between training, competition and recovery (Silva *et al.*, 2011:48).

2. PROBLEM STATEMENT

Rugby has become such a large profession that players often have to compete every 7 days for several weeks, increasing the training load and imposing a great physiological stress on their bodies (Van Wyk & Lambert, 2009:1). It can therefore be expected that these repetitive bouts of play may have a negative impact on performance as a result of large training volumes without sufficient rest and recovery time between training sessions (Coffey *et al.*, 2004:1). This is clearly demonstrated by Holtzhausen *et al.* (2006:1261) reporting 62 injuries in 48 players over a period of 14 weeks, with 41 of these injuries taking place during a match, (resulting in 11 injuries per 1 000 hours of exposure). Researchers reported a significant increase in Blood lactate (BLa^-) and plasma potassium (K^+) concentration and decreased plasma sodium (Na^+) concentration (Takarada, 2003:417), as well as a significant reduction in pH^- and Bicarbonate (HCO_3) values ($p = 0.0\text{-}0.04$) after a rugby match and rugby simulated exercise (Pointon & Duffield, 2012:211). Due to the above mentioned evidence, research has shifted focus towards recovery and the enhancement thereof to improve performance (Hamlin, 2007:398).

Recovery, can be defined as the process of the muscles returning to its pre-exercising state following exercise (Tomlin & Wenger, 2001:2) is a crucial element to prevent the player from developing fatigue and sustaining an injury (Hing *et al.*, 2008:148). The ultimate goal of an effective physiological recovery period is to repair damaged tissue, replenish depleted energy stores and remove accumulated metabolites, which will in turn result in less fatigue and allowing the effects of training to be maximized (Hamlin, 2007:398). A large predictor of recovery is the occurrence of delayed onset muscle soreness (DOMS). DOMS is a familiar experience for athletes with symptoms ranging from slight muscle stiffness to severe debilitating pain resulting in restricted movement (Cheung *et al.*, 2003:147). Muscle soreness and damage will often occur after selective exercise routines, peaking 24–48 hours after training and usually subsiding within 96 hours post exercise (Connolly *et al.*, 2003:197).

Gill *et al.* (2006:261) reported that passive recovery (PAR) had the least-effective post-match recovery rate (39%) in creatine kinase (CK) levels ($p < 0.01$) compared to active recovery modalities (88%) after an 80 minute rugby match. These results indicate that other possible recovery techniques should be investigated in order to optimize recovery, which in turn may maximize performance. Two popular active interventions used by athletes to increase recovery and normalize the changes that have occurred in the internal environment, is contrast water therapy (CWT) and cold water immersion (CWI) (Stanley *et al.,* 2012:951).

CWI, also known as cryotherapy, is commonly used following acute musculoskeletal injuries to induce vasoconstriction and is believed to enhance both physiological and perceptual recovery (Pournot *et al.*, 2011:1288). The foundation for using CWI is R.I.C.E. (rest, ice, compression and elevation) (Cheung *et al.,* 2003:153) and is proposed to reduce the inflammatory response to injured tissue as well as decrease oedema, haematoma formation and pain (Burgess & Lambert, 2010:258). Brophy-Williams *et al.* (2011:668) found a 79% more beneficial effect ($p = 0.079$), when CWI was applied immediately after a Yo-Yo intermittent test in football and hockey players (age: 21 years) when compared with a control group. Complimentary to these results, Ascensão *et al.* (2011:221) showed that the immediate application of CWI following a soccer-match, resulted in lower perceived muscle soreness and temporary recovery of strength ($p < 0.05$) after 24 hours of recovery. However, other researchers reported contrasting results of either no improvement (Bailey *et al.*, 2007:1166) or a 27% statistical significant decrease ($p < 0.01$ in vertical jump height) (Ferretti *et al.,* 1992:113). In addition, other researchers reported no significant differences in blood pH, HCO_3, K^+, Na^+ or Partial Saturated Oxygen (PSO_2) levels except in Partial Oxygen levels (PO_2) ($p < 0.05$) in recreational, sedentary and endurance cycling participants post-CWI following an intermittent shuttle run and cycling in the heat test (Halson *et al*,. 2008:337). In contrast to these results, Banfi *et al.* (2009:191) reported that the application of CWI caused a statistically significant ($p < 0.01$) decrease in haemoglobin values with no difference in haematocrit values after a daily training session (consisting of maximal training, submaximal effort and submaximal training in the morning and afternoon) in male rugby players aged 26 years. According to Ingram *et al.* (2009:419), CWI is more effective than CWT as indicated by muscle soreness ratings ($d = 0.4$) and improved speed recovery ($p < 0.05$) in eleven male team-sport athletes (aged 27.5 years).

CWT has a long history of usage as a recovery aid by the sports medicine community (Higgins & Kaminski, 1998:336). CWT is a combination of cold- (CWI) and heat- (thermotherapy) modalities, usually alternating between immersions in warm and cold water (Higgins & Kaminski, 1998:336). The theory behind CWT is to stimulate area-specific blood flow, increase blood lactate removal, reduce inflammation and oedema, provide relief from stiffness and pain (Wilcock *et al*., 2006:760) as well as to stimulate the central nervous system (Cochrane, 2004:27). There is, however, no scientific evidence for either ending with warm or cold water. Studies reported that CWT resulted in an improved recovery in maximal voluntary contraction and countermovement jump ($p > 0.05$), (Pournot *et al.*, 2011:1292) and a non-significant decreased CK level ($p > 0.01$) (Gill *et al.*, 2006:261) in rugby players (aged 22–25 years) one hour after exercise. A lowered post-exercise BLa^- level ($p < 0.001$–0.05) and improved perception of recovery ($p < 0.001$) after an intense anaerobic Wingate Test was also demonstrated as a result of CWT in highly active male individuals and hockey players (aged 16–26 years) (Coffey *et al.*, 2004:7; Sayers *et al.*, 2011:298). Gill *et al.* (2006:261) reported an 85% CK recovery ($p > 0.01$) to base-line values 84 hours after the application of CWT as a recovery modality.

Research suggests that CWT is superior to PAR which requires participants not to engage in any form of recovery (Coffey *et al.*, 2004:8; Elias *et al.*, 2012:361; Gill *et al.*, 2006:261) This is supported by studies showing a higher BLa^- concentration ($p < 0.001$) and lower blood pH levels after PAR (Sayers *et al.*, 2011:298). However, no significant difference ($p \geq 0.05$) was observed between recovery modalities (Coffey *et al.*, 2004:8) after PAR in hockey players and active individuals but a larger success was seen in CWI and CWT at 1, 24 and 48 hours after recovery in football players (Elias *et al.*, 2012:361).

Most studies to date have only focused on utilizing one of these recovery techniques or on the acute effect thereof and have not made use of both the modalities to optimize recovery over a longer period. They also mainly focused on either the physical or the haematological variables, and not on both. It is in the light of the above mentioned that the following research questions are posed: “What is the effect of CWI compared to PAR over a 48-hour recovery period on certain physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players?” Secondly, “What is the effect of CWT compared to PAR over a 48-hour recovery period in certain physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players?” This information will be beneficial to all sport scientists, biokineticists, sport coaches and other sport professionals to optimize recovery time for players so that optimal performance can be achieved.

3. OBJECTIVES

The objectives of this study are:

- To determine the effects of CWI compared to PAR over a 48-hour period on physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players.
- To determine the effects of CWT compared to PAR over a 48-hour period on physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players.

4. HYPOTHESES

- CWI will have a practically significant negative effect on the vertical jump and grip strength but a statistically significant positive effect on the BLa$^-$, pH, haemoglobin, haematocrit, Na$^+$, K$^+$, PO$_2$, PCO$_2$, HCO$_3$ and base excess levels compared to PAR.
- CWT will have a practically significantly positive effect on the vertical jump and grip strength test as well as on the BLa$^-$, pH, haemoglobin, haematocrit, Na$^+$, K$^+$, PO$_2$, PCO$_2$, HCO$_3$ and base excess levels as opposed to PAR.

5. STRUCTURE OF THE DISSERTATION

The dissertation will be submitted in article format as approved by the Senate of the North-West University and will be structured as follows:

Chapter 1: Introduction. A bibliography is provided at the end of the chapter in accordance with the guidelines of the North-West University.

Chapter 2: Literature overview: Effects of various hydrotherapy recovery interventions on a variety of physical and physiological variables after strenuous training. A bibliography is provided at the end of the chapter in accordance with the guidelines of the North-West University.

Chapter 3: Article 1: The effect of cold water immersion over a 48-hour recovery period after an intense anaerobic session in a cohort of male university-level rugby players. This article will be presented for possible publication in the *Journal of Strength and Conditioning Research*. A bibliography is presented at the end of the chapter in accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables and figures will be included within the text so as to make the article easier to read and understand. Furthermore, the line spacing of the article will be set at 1.5 as the journal has set no guidelines for authors in order to ensure consistency right through the document.

Chapter 4: Article 2: The effect of contrast water therapy over a 48-hour recovery period after an intense anaerobic session in a cohort of male university-level rugby players. This article will be presented for possible publication in the *Journal of Science and Medicine in Sport*. A bibliography is presented at the end of the chapter in accordance with the guidelines of the journal. Although not according to the guidelines of the journal, tables and figures will be included within the text so as to make the article easier to read and understand. Furthermore, the line spacing of the article will be set at 1.5 instead of the prescribed 2 lines in order to ensure consistency right through the document.

Chapter 5: Summary, conclusion, limitations and recommendations.

Appendix A: Language editing letter

Appendix B: Informed consent form and general demographic and information questionnaire

Appendix C: Anthropometric, physical and haematological performance data collection forms

Appendix D: Instructions for authors from the journal of strength and conditioning research and journal of science and medicine in sport.

6. REFERENCES

Ascensão, A., Leite, M., Rebelo, A.N., Magalhaes, S. & Magalhaes, J. 2011. Effects of cold water immersion on the recovery of physical performance and muscle damage following a one-off soccer match. *Journal of sport science,* 29(3):217-225.

Bailey, D.M., Erith, S.J., Griffin, P.J., Dowson, A., Brewer, D.S., Gant, N. & Williams, C. 2007. Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. *Journal of sport sciences*, 25(11):1163-1170.

Banfi, G., Melegati, G., Barrasi, A. & Melzi d'Eril, G. 2009. Beneficial effects of the whole-body cryotherapy on sport haemolysis. *Journal of human sport and exercise,* 4(2):189-193.

Brooks, J.H.M., Fuller, C.W., Kemp, S.P.T. & Reddin, D.B. 2005. Epidemiology of injuries in English professional rugby union: part 1 match injuries. *British journal of sports medicine,* 39(10):757-766.

Brophy-Williams, N., Landers, G. & Wallman, K. 2011. Effect of immediate and delayed cold water immersion after a high intensity exercise session on subsequent run performance. *Journal of sport science and medicine,* 10(4):665-670.

Burgess, T.L. & Lambert, M.I. 2010. The efficacy of cryotherapy on recovery following exercise-induced muscle damage. *Sports medicine journal*, 11(2):258-277.

Cheung, K., Hume, P.A. & Maxwell, L. 2003. Delayed onset muscle soreness. *Sports medicine,* 33(2):145-164.

Cochrane, D.J. 2004. Alternating hot and cold water immersion for athlete recovery: a review. *Physical therapy in sport*, 5(1):26-32.

Coffey, V., Leveritt, M. & Gill, N. 2004. Effect of recovery modality on 4-hour repeated treadmill running performance and changes in physiological variables. *Journal of science and medicine in sport*, 7(1):1-10.

Connolly D.A.J., Sayers S.P. & McHugh M.P. 2003. Treatment and prevention of delayed onset muscle soreness. *Journal of strength conditioning research*, 17(1):197–208.

Deutsch M.U., Maw, G.J., Jenkins, D. & Reaburn, P. 1998. Heart rate, blood lactate and kinematic data of elite colts (under-19) union players during competition. *Journal of sports sciences,* 16(6):561-570.

Duthie, G., Pyne, D. & Hooper, S. 2003. Applied physiology and game analysis of rugby union. *Sports medicine*, 33(13):973-991.

Elias, G.P., Varley, M.C., Wyckelsma, V.L., McKenna, M.J., Minahan, C.L. & Aughey, R.J. 2012. Effects of water immersion on posttraining recovery in Australian footballers. *International journal of sports physiology and performance,* 7(4):357-366.

Ferretti, G., Ishii M., Moia C. & Cerretelli P. 1992. Effects of temperature on the maximal instantaneous muscle power of humans. *European journal of applied physiology and occupational physiology*, 64(2):112-116.

Gill, N.D., Beaven, C.M. & Cook, C. 2006. Effectiveness of post-match recovery strategies in rugby players. *Sports medicine,* 40(3):260-263.

Halson, S.L., Quod, M.J., Martin, D.T., Gardner, A.S., Ebert, T.R. & Laursen, P.B. 2008. Physiological responses to cold water immersion following cycling in the heat. *International journal of sports physiology and performance,* 3(3): 331-346.

Hamlin, M.J. 2007. The effect of contrast temperature water therapy on repeated sprint performance. *Journal of science and medicine in sport,* 10(6):398-402.

Higgins, D. & Kaminski, T.W. 1998. Contrast therapy does not cause fluctuations in human gastrocnemius intramuscular temperature. *Journal of athletic training,* 33(4):336-340.

Hing, W.A., White, S.G., Bouaaphone, A. & Lee, P. 2008. Contrast therapy - A systematic review. *Physical therapy in sport,* 9(3):148-161.

Holtzhauzen, L.J., Schwellnus, M.P., Jakoet, I. & Pretorius, A.L. 2006. The incidence and nature of injuries in South African rugby players in the rugby super 12 competition. *South African medical journal*, 96(12):1260-1265.

Ingram, J., Dawson, B., Goodman, C., Wallman, K. & Beilby, J. 2009. Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of science and medicine in sport,* 12(3):417-421.

Pointon, M. & Duffield, R. 2012. Cold water immersion recovery after simulated collision sport exercise. *Medicine and science in sports and exercise,* 44(2):206-216.

Pournot, H., Bieuzen, F., Duffield, R., Lepretre, P.M., Cozzolino, C. & Hausswirth, C. 2011. Short term effects of various water immersions on recovery from exhaustive intermittent exercise. *Journal of applied physiology*, 111(7):1287-1295.

Sayers, M.G., Calder, A.M. & Sanders, J.G. 2011. Effect of whole-body contrast-water therapy on recovery from intense exercise of short duration. *European journal of sport science,* 11(4):293-302.

Silva, R., Cleto, L., do Valle, N., Gripp, F., Rocha-Vieira, E. & Pinto, K. 2011. Effect of water immersion on post-exercise recovery from a single leg bout of aerobic exercise. *Journal of exercise physiology*, 14(6):47-53.

Stanley, J., Bucheit, M. & Peake, J.M. 2012. The effect of post-exercise hydrotherapy on subsequent exercise performance and heart rate variability. *European journal of applied physiology,* 112(3):951-961.

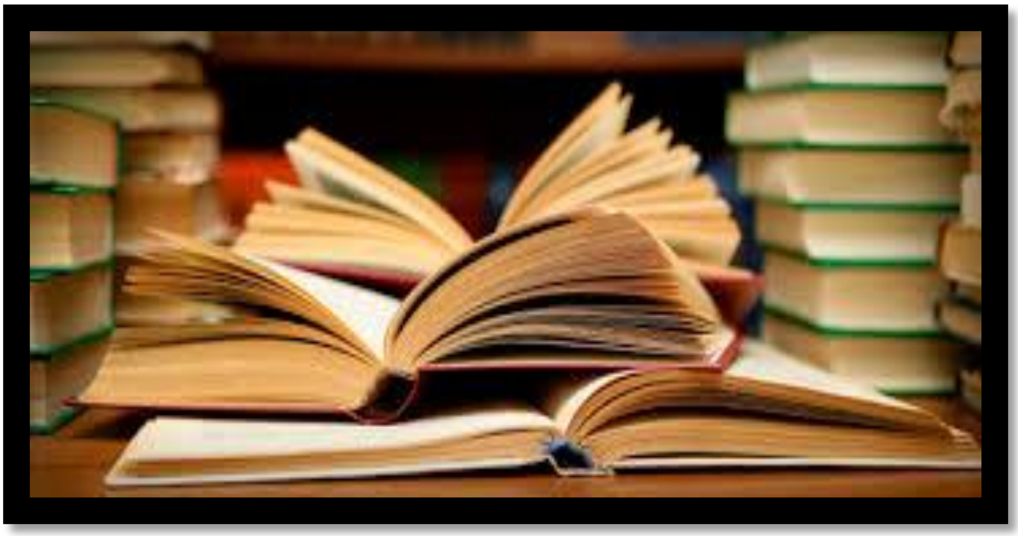
Takarada, Y. 2003. Evaluation of muscle damage after a rugby match with special reference to tackle plays. *British journal of sports medicine,* 37(5):416-419.

Tomlin, D.L. & Wenger, H.A. 2001. The relationship between aerobic fitness and recovery from high intensity intermittent exercise. *Sports medicine,* 31(1):1-11.

Van Wyk, D. & Lambert, M.I. 2009. Recovery strategies implemented by sport support staff of elite rugby players in South Africa. *South African journal of physiotherapy,* 65(1):1-6.

Wilcock, I. M., Cronin, J.B. & Hing W.A. 2006. Physiological response to water immersion. A method for sport recovery? *Sports medicine*, 36(9):747-765.

CHAPTER 2



2

LITERATURE OVERVIEW: EFFECTS OF VARIOUS HYDROTHERAPY RECOVERY INTERVENTIONS ON A VARIETY OF PHYSICAL AND PHYSIOLOGICAL VARIABLES AFTER STRENUOUS TRAINING

5. SUMMARY OF THE STUDIES REGARDING CWI AND CWT

5.1. CWI versus CWT

5.2. Temperature

5.3. Duration

5.4. Immersion depth

5.5. Physical test parameters

5.6. Physiological parameters

6. CONCLUSION

7. REFERENCES

1. INTRODUCTION

Elite athletes are exposed to exhaustive training and competition on a daily basis, usually on consecutive days or multiple days a week, placing a great demand on their cardiorespiratory and metabolic systems (Bahnert *et al.*, 2013:151; King & Duffield, 2009:1795; Stanley *et al.*, 2014:148). Exposure to matches has increased over the years, with players participating weekly for several weeks over a full competitive season, placing their bodies in a state of disrepair (Van Wyk & Lambert, 2009:1). Exhaustive training and competition can ultimately fatigue the musculoskeletal, nervous and metabolic systems and produce delayed onset muscle soreness (DOMS) (Ingram *et al.*, 2009:417). Energy substrate depletion, mechanical muscle damage, oxidative stress, hyperthermia and inflammation commonly occur due to intensive exercise (Leeder *et al.*, 2011:233) and may lead to a decrease in sport performance. Rest is a component easily overlooked when increasing the intensity, volume and overload to find the competitive edge above the opposition (Cochrane, 2004:26). If a deficiency in this recovery period takes place, it may result in an athlete not being able to complete the training load or train at the prerequisite intensity at the subsequent training sessions or match (Van Wyk & Lambert, 2009:1). In order to maintain high-level performance and obtain a competitive edge on a daily or weekly basis, the necessary recovery should therefore take place (Cochrane, 2004:26).

Various recovery interventions exist and are aimed at targeting the potential mechanisms of injury to maximize performance, minimize the recovery period and prevent injuries (Connolly *et al.*, 2003:198). Recovery interventions include hydrotherapy (cold water immersion, contrast water therapy, thermotherapy or water immersion *per se*) (Wilcock *et al.*, 2006:748), stretching, anti-inflammatory drugs, ultrasound, electrical current techniques, homeopathy, massage, compression, hyperbaric oxygen, exercise and passive rest (Cheung *et al.*, 2003:153; Connolly *et al.*, 2003:198). This being said, the use of water or hydrotherapy is the most popular intervention (Bleakley & Davison, 2009:179) with the recovery interventions of cold water immersion (CWI) and contrast water therapy (CWT) being the best known among the sporting fraternity (Pournot *et al.*, 2011:1288; Stanley *et al.*, 2012:951). The popularity of these interventions was highlighted by a survey on French professional soccer teams' recovery strategies which revealed that CWI and CWT were the two most commonly used interventions, utilized by 88% of soccer teams investigated (Nédélec *et al.*, 2013:12), with CWI probably being the most popular (Van Wyk & Lambert, 2009:1).

Despite numerous publications on the use of water immersion as a post-exercise recovery intervention, inconsistencies exist with regard to the exact protocols used and the reported benefits of these techniques (Breger Stanton *et al.*, 2009:57, 68; Elias *et al.*, 2012:357; Myrer *et al.*, 1994:320).

It is in the light of the shortcomings mentioned above that this literature review was undertaken. The first aim of this literature overview is to provide the reader with a brief summary of the physiology of training, recovery and muscle injury, and secondly, to discuss the different factors affected by hydrotherapy. Thirdly, it is to provide a summarized comparison of the two techniques from the literature findings with regard to the effects of CWI and CWT as well as a comparison between these techniques, and lastly, to determine whether CWI or CWT is most suited to enhance recovery and performance as well as decrease fatigue and the potential risk of injuries in the sporting fraternity.

Searches were narrowed down to only include articles in the tables from the past 10 years (2004-2014) that have investigated the influence of CWI, CWT or PAR (passive recovery) on various physical, physiological and performance variables in athletes for comparison reasons. Furthermore, only studies which made use of adult populations (age: ≥ 18 year) as test subjects were included. Key words used during the searches included, but were not limited to, the following: cold water immersion, contrast water therapy, hydrotherapy, passive recovery, physical variables, and physiological variables. Computer searches were performed using the SportsDiscus, Medline, Academic Research, Academic Search Premier and Masterfile databases. The MetaCrawler, Scirus and Google Scholar internet search engines were also used to trace the available literature.

In the subsequent section a brief overview of the physiology of training, recovery and muscle injury will be discussed, followed by the factors influenced by hydrotherapy, after which the different hydrotherapy interventions will be discussed to provide the reader with the background information necessary to interpret the findings of the different research articles.

2. ELEMENTS OF TRAINING AND RECOVERY

Recovery can be defined as the process during which muscles return to their pre-exercising state after exercise (Tomlin & Wenger, 2001:2). Recovery is a vital period between episodes of training and competitions to prevent subjects from developing long-term fatigue and overtraining as well as from sustaining injuries (Hing *et al.*, 2008:148). The physiological stress caused by intense exercise includes energy substrate depletion, hyperthermia, oxidative stress, inflammation, nervous system fatigue and mechanical muscle damage (Leeder *et al.*, 2011:233). When muscle damage occurs, the severity thereof can fluctuate from a slight micro injury of a small number of muscle fibres to a disruption of a whole muscle (Nédélec *et al.*, 2012:1000). Muscle damage will lead to muscle soreness which can be categorized into transitory soreness, felt during or immediately after training, and delayed onset muscle soreness (DOMS), which may last for a few days after training (Smith, 1992:135). The ultimate goal of effective recovery is to repair damaged tissue, replenish depleted energy stores and remove accumulated metabolites, so that less fatigue is experienced and the effects of training maximized (Hamlin, 2007:398). Nevertheless, in order to understand the need for recovery and the mechanisms that underlie the recovery process, the next section will be dedicated to the causes of DOMS as well as the physiological consequences of DOMS.

DOMS is a familiar experience for all athletes with symptoms ranging from slight muscle stiffness to debilitating pain which may restrict movement (Cheung *et al.*, 2003:147). The pain stimulus associated with DOMS can be caused by numerous factors, which also include lactic acid build-up, elevated muscle stiffness, muscle spasm, inflammation, enzyme efflux and connective tissue damage (Cheung *et al.*, 2003:147; Kaczmarek *et al.*, 2013:35). A disruption in muscle contractile processes accompanied by less efficient transport and metabolic pathways will occur due to the rise in lactate production and H^+ accumulation (Tomlin & Wenger, 2001:2). Muscle soreness and damage will often occur after selective exercise routines peaking 24–48 hours after training exposure and usually subsiding within 96 hours (Connolly *et al.*, 2003:197; Smith, 1992:135). Specific conditions of the exercise (e.g. eccentric training) and intrinsic factors of the player (e.g. the length of the exercising muscle) will determine the severity and duration of the symptoms (Connolly *et al.*, 2003:198). DOMS especially occurs after activities involving eccentric muscle actions such as downhill running, activities which require a crouched position for a large portion of the movement, jump-like activities and many bending, lowering and braking-type movements (Smith, 1992:136). Although the negative phase of the movement is perceived to be less stressful than the concentric phase, it is this portion of the exercise that leads to the greatest amount of muscle soreness (Smith, 1992:136). Muscle damage caused by this high intensity eccentric activities are associated with decrements in muscle function and exercise performance and will initiate an inflammatory response (Connolly *et al.*, 2003:199).

This inflammatory response, which is a systematic response known as the acute phase, leads to prostaglandin, leukotriene en cytokine production as well as the occurrence of oedema as a result of micro trauma to the muscle fibres (Connolly *et al.*, 2003:199; Kaczmarek *et al.*, 2013:37; Nédélec *et al.*, 2012:1009). This prostaglandin E_2 sensitizes type III and IV pain afferents through chemical stimuli, causing the sensation of pain. Leukotrienes will increase vascular permeability, attracting neutrophils to the damaged site which will generate free radicals, thereby exacerbating the damage to the cell membrane (Connolly *et al.*, 2003:197). Connolly and co-workers (2003:198) gave the following schematic representation of the possible sequence of injury and DOMS.

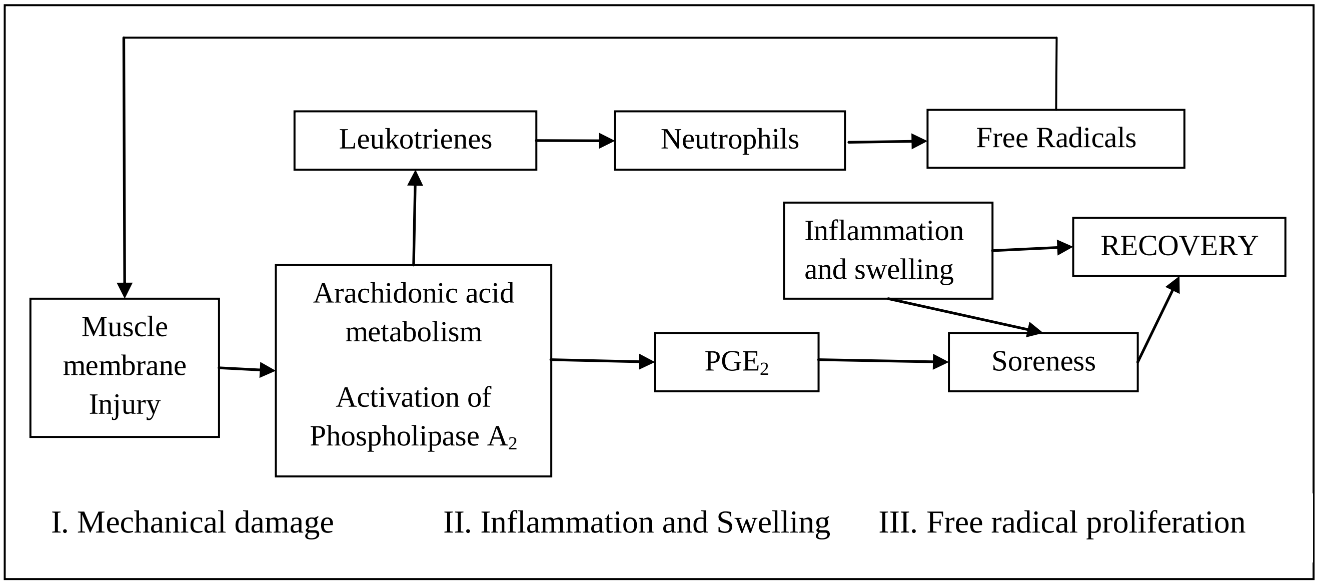


FIGURE 1: Adapted schematic representation of the possible sequence of injury and DOMS (Connolly *et al.*, 2003:198)

The recovery process consists of two components, namely a fast and slow component. According to Gaesser and Brooks (cited by Tomlin and Wenger 2001:2) the fast phase lasts approximately 10 seconds / few minutes, and is marked by a rapid decline in oxygen consumption and heart rate, (replenishing tissue stores with oxygen and muscle-ATP as well as phosphocreatine). On the other hand the second component, the slow phase, will continue for as long as 24 hours before returning to the original resting levels, and is characterized by the removal of lactate and hydrogen ions, elevated core temperature and an increase in cardiac and respiratory function.

Thus it can be concluded that the ultimate goal of an effective recovery period is to repair damaged tissue, replenish depleted energy stores and remove accumulated metabolites, which will in turn result in less fatigue, so that the effects of training can be maximized (Hamlin, 2007:398). This is confirmed by Cleak and Eston (1992:333) who reported that most recovery modalities either focus on the reduction of inflammation and oedema that were caused by tissue damage and/or break up the cycle thought to initiate the tonic muscle spasm or pain.

3. FACTORS AFFECTING HYDROTHERAPY

Water was first used as a recovery aid by Hippocrates, as far back as 460-370 BC and was considered to be more than just a simple hygienic measure (Meeusen & Lievens, 1986:398; Van Tubergen & Van der Linden, 2002:273). Thermal baths were recommended for the treatment of particular medical-related conditions, such as soothing chest pain, relieving fatigue, relaxing joints, promoting good respiration and curing headaches

(Jackson, 1990:1). According to literature, the term hydrotherapy is a combined phrase derived from two Greek words, "Hydro" meaning water and "Therapeuein" meaning therapy (Bosman *et al.,* 2011:26, 52). However, a variety of factors should be considered before water is used as a recovery aid. These factors will be discussed in the subsequent section.

3.1. Hydrostatic pressure of water

Hydrostatic pressure can be defined as the compressive force of water on an immersed body resulting in a displacement of fluids from the periphery intracellular space into the blood towards the central cavity along with venous return (Kaczmarek *et al.,* 2013:36; Sayers *et al.,* 2011:294; Vaile *et al.,* 2008a:452; Wilcock *et al.,* 2006:750). The degree of the hydrostatic pressure which the body experiences will increase as the depth of immersion increases, although gravity has a smaller effect on immersion (Kaczmarek *et al.,* 2013:36; Wilcock *et al.,* 2006:750). Vaile and colleagues (2008a:453) acknowledged that the changes in the intracellular-intravascular osmotic gradients, due to hydrostatic pressure, may increase the removal of waste products such as blood lactate and creatine kinase, and help with the enhancement of recovery.

Furthermore, the hydrostatic pressure of water immersion may lead to a decrease in systematic vascular capacity which will trigger a redistribution of peripheral blood volume into the intrathoracic vascular network, favouring venous return into the heart (Boussuges *et al.,* 2007:272) and mediating haemodynamic changes (Weston *et al.,* 1987:615). Boussuges and colleagues (2007:273) also concluded that an increase in hydrostatic pressure due to water immersion will result in a shift of the interstitial fluid through the capillary walls and an accompanying increase in plasma volume in the portion of the immersed body. A change in plasma volume can be attributed to haemodilution (increased diffusion and re-absorption) as well as blood displacement within the body (Wilcock *et al.,* 2006:753). Diffusion is responsible for the largest exchange of fluids and substances by moving from a high to low concentration along the capillary membrane (Wilcock *et al.,* 2006:752). According to Datta and Tipton (2006:2057), the difference in the hydrostatic pressure of water over the immersed body, has a direct effect on the ventilatory responses of the body. They reported that a negative transthoracic pressure of 14.7 mmHg resulted in a negative breathing pressure and a 65% increase in the work of breathing may be during body immersion in water (Datta & Tipton, 2006:2057, 2058). However, some researchers claim that a low water temperature in combination with the hydrostatic pressure of water is responsible for the overall recovery that can be achieved by the participant (Vaile *et al.,* 2008a:454).

The combined effects of water's hydrostatic pressure and low temperature may result in muscular and vascular compression which may assist in reducing early onset of swelling, inflammation (Cochrane, 2004:27), pain and oedema, due to the removal of accumulated fluid and metabolites from the inflamed superficial tissue (Enwemeka *et al.,* 2002:48). The combined effects of these factors may also lead to an increase in the translocation of substrates from the muscles, increased cardiac output, stroke volume and a decrease in systematic peripheral and vascular resistance, which may lead to a greater muscular blood flow without a corresponding increase in heart rate (Sayers *et al.,* 2011:294; Wilcock *et al.,* 2006:750). Śråmek and associates (2000:439) found that changes in diuresis and plasma renin activity could be attributed to the hydrostatic pressure of water rather than to the low temperature of the water. It is in view of these claims that the following section will be dedicated to the possible effects of water temperature on the body and the body's responses during water immersion.

3.2. Water temperature

A change in water temperature may influence the body's thermoregulatory response during immersion. For example, warm water immersion (WWI) will cause the body's temperature to rise above 37°C (normal internal body temperature at rest); stimulate the hypothalamus in order to decrease sympathetic nerve drive, causing vasodilatation in skin blood vessels and also cause an increase in blood circulation (Cochrane, 2004:27; Wilmore *et al.,* 2008:258). An increase in blood flow may increase the rate of tissue healing due to an increased in the provision of protein, nutrients and oxygen to the injured tissue (Nadler *et al.,* 2004:397). The opposite occurs during cold exposure when skin and blood temperature decrease and vasoconstriction of skin blood vessels take place, thereby decreasing the amount of blood in the superficial tissues (Enwemeka *et al.,* 2002:49; Wilmore *et al.,* 2008:270). The initial response of the body to CWI, namely cold shock, is evoked by the large and rapid fall in skin temperature due to heat loss (Datta & Tipton, 2006:2058).

The primary means to avoid this resultant excessive heat loss is peripheral vasoconstriction, non-shivering thermogenesis and shivering (Wilmore *et al.,* 2008:270). In this regard, Tikuisis and associates (2002:55) showed that immersion in water at a temperature of 18°C for 90 min resulted in subjects shivering at 61% and 69% of their maximal shivering capacity. Shivering of this magnitude has the same response as light exercise (Śråmek *et al.,* 2000:440). Śråmek and associates (2000:438) reported that immersion in water of 14°C for an hour will decrease body temperature by 1.7°C, thereby stimulating cold-induced thermogenesis and activating the sympathetic nervous system. In turn, sympathetic nervous system activation will lead to an increase ($p = 0.003$) in noradrenaline and dopamine concentrations (up to 530% and 250%, respectively) resulting in higher ($p = 0.001$) heart rate, blood pressure and metabolic rate (up to 93%) (Śråmek *et al.,* 2000:437). In addition to this, an increased metabolism and heat production can be accomplished by non-shivering thermogenesis. Non-shivering thermogenesis is caused by an increase norepinephrine level and sympathetic innervation, which activate the thermogenic cells (adipocytes) that maintain body temperature

(Rousset *et al.,* 2004:131). These brown adipocytes have a high content of mitochondria (that is also involved in thermogenesis) which is filled up to 8% with uncoupling protein-1 in the inner-membrane. Uncoupling protein-1 in turn is initiated by exposure to cold to dissipate energy of substrate oxidation into heat (Rousset *et al.,* 2004:130,132). Another system affected by CWI is the central nervous system (CNS) (Kaczmarek *et al.,* 2013:37)

A reduction in nerve conduction velocity, inhibition of the pain spasm cycle as well as mechanoreceptor activity, which includes muscle spindle activity and a blunted stretch-reflex response, can be expected as a result of decreased muscle temperatures (Kaczmarek *et al.,* 2013:37; Meeusen & Lievens, 1986:398). This is due to a decrease in acetylcholine production (Kaczmarek *et al.,* 2013:37) which can be detrimental to performance (for example maximal anaerobic power) (Ferretti, 1992:186). In addition to the pain spasm cycle, lower water temperatures will diminish the firing rates of pain and temperature sensory receptors located in the skin and thereby reduce the sensation of pain (Enwemeka *et al.,* 2002:48).

According to Breger Stanton and colleagues (2009:57), CWT temperatures vary between 7 and 22°C and 26 and 45°C for cold and warm water, respectively. A rise in water temperature to between 37 and 39°C led to significant increases in cardiac output ($p < 0.0001$), stroke volume ($p < 0.001$) and heart rate ($p < 0.001$) as well as a decrease in blood diastolic pressure and total peripheral resistance (31%, 53% and 65% at temperatures of 35°C, 37°C and 39°C respectively) in nine healthy men and seven women (mean aged 34 years) (Weston *et al.,* 1987:614). Weston and co-workers (1987:614) alleged that the variation in water temperatures during CWT produced a complex series of changes, including alterations in pulse pressure, mean blood pressure and peripheral resistance, resulting in baroreceptor stimulation. They further stated that an increase in myocardial contractility was directly related to the raised body-core temperature, but also speculated that sympathetic nervous system activity and hormonal factors may have been involved (Weston *et al.,* 1987:614).

Table 1 contains a summary of physiological and physical components that are influenced by either warm or cold exposure as well as the way in which each of these components are influenced.

Table 1: The effect of warm or cold exposure on different physiological and physical components of the body.

Cold exposure	Warm exposure
↑ Vasoconstriction (Burke *et al.*, 2000:21)	↑ Vasodilatation (Burke *et al.*, 2000:21)
↓ Blood flow (Nadler *et al.*, 2004:395)	↑ Blood flow (Nadler *et al.*, 2004:397)
↓ Plasma volume (Gordon *et al.*, 2003:472)	↑ Plasma volume (Gordon *et al.*, 2003:472)
↓ Swelling (Cochrane, 2004:27)	↔ Swelling (Vaile *et al.*, 2008a:450)
↓ Inflammation (Nadler *et al.*, 2004:395)	↑ Inflammation (Nadler *et al.*, 2004:397)
↓ Metabolism (Nadler *et al.*, 2004:395)	↑ Metabolism (Nadler *et al.*, 2004:397)
↑ Blood pressure (Śråmek *et al.*, 2000:437)	↓ Blood pressure (Śråmek *et al.*, 2000:437)
↑ Heart rate (Śråmek *et al.*, 2000:437)	↓ Heart rate (Śråmek *et al.*, 2000:437)
↑ Aldosterone levels (Śråmek *et al.*, 2000:438)	↓ Aldosterone levels (Śråmek *et al.*, 2000:438)
↓ Cortisol levels (Śråmek *et al.*, 2000:438)	↓ Cortisol levels (Śråmek *et al.*, 2000:438)
↔ Plasma renin activity (Śråmek *et al.*, 2000:438)	↔ Plasma renin activity (Śråmek *et al.*, 2000:438)
↔ Plasma protein (Na^+, K^+) (Stocks *et al.*, 2004:7)	↔ Plasma protein (Na^+, ↑ K^+) (Stocks *et al.*, 2004:7)
↓ Creatine Kinase (Vaile *et al.*, 2008a:450)	↓ Creatine Kinase (Vaile *et al.*, 2008a:450)
↔ Lactate and Lactate dehydrogenase (Silva *et al.*, 2011:49; Vaile *et al.*, 2008a:450)	↔ Lactate and Lactate dehydrogenase (Silva *et al.*, 2011:49; Vaile *et al.*, 2008a:450)
↔ Myoglobin (Vaile *et al.*, 2008a:450)	↔ Myoglobin (Vaile *et al.*, 2008a:450)
↓ Myocellular neurosis (Ingram *et al.*, 2009:419)	↑ Antioxidant and antibody supply (Ingram *et al.*, 2009:419)
↑ Sympathetic nervous system (Śråmek *et al.*, 2000:438)	↓ Sympathetic nerve drive (Cochrane, 2004:27)
↓ Muscle spindle activity (Kaczmarek *et al.*, 2013:36)	↑ Central nervous system (Cochrane, 2004:27)
↓ Neuromuscular coordination (Ferretti *et al.*, 1992:114)	↑ Neuromuscular coordination (Ferretti *et al.*, 1992:114)
↓ Nerve conduction velocity (Ferretti *et al.*, 1992:114)	↑ Nerve conduction velocity (Ferretti *et al.*, 1992:114)
↓ Muscle spasticity (Kaczmarek *et al.*, 2013:36)	↑ Muscle relaxation (Burke *et al.*, 2000:22)
↑ Collagen stiffness (Burke *et al.*, 2000:21)	↓ Collagen stiffness (Burke *et al.*, 2000:22)
↓ Maximal anaerobic power (Ferretti, 1992:114)	↔ Maximal anaerobic power (Ferretti, 1992:114)

↑ Increase ↓ Decrease ↔ Unchanged

Water temperature is not the only factor that influences the effects of water immersion, the duration of immersion also needs to be considered.

3.3. Duration of water immersion

The main focus of either WWI or CWI should be to increase or reduce tissue temperature without damaging sensitive structures such as the superficial nerves or cause inflammation (Holcomb, 2005:60; Wilcock *et al.*, 2006:760). A review by Breger Stanton *et al.* (2009:58) showed that the universal duration ratio (minutes) for warm to cold-water therapy in the treatment of any injury is in most instances 3:1 or 4:1. However, a recent review compiled by Versey and colleagues (2013) demonstrated a 1:1 and 1:2 ratio in minutes to be the most widely used amongst researchers. Versey and colleagues (2011) illustrated that the most popular total immersion duration applied vary between 10 and 15 minutes for either CWI or CWT. In this regard, Wilcock and associates (2006:760) stated that an average of 2–5 repetitions should be completed when relocating between water pools.

The following factors, however, should also be considered when deciding on the duration of application: type of cold medium (e.g. ice, water or air); compression (e.g. compression garments or clothing); location of treatment (e.g. total body immersion or immersion up to a certain mark); temperature (of the medium), thickness of subcutaneous tissue (relative fat percentage) and the participant’s sensitivity to cold (Holcomb, 2005:60) as one or more of these factors may have an influence on recovery.

3.4. Body composition and other factors

An important consideration when establishing and applying a hydrotherapy protocol is the intra- and inter-individual differences in the cold response (Xu *et al.*, 2007:79). When hydrotherapy is used as a recovery modality, an assortment of factors should be considered as "cold shock" may possibly have a negative effect on the participant’s recovery, and subsequently, a detrimental effect on sport performance (Datta & Tipton, 2006:2058). According to Xu *et al.* (2007:79) body height, body weight, shivering capacity, blood flow rate, immersion depth and body fat percentage could impact either the physiological (vasoconstriction, vasodilatation and shivering) or the biophysical responses (heat transfer from the core to the body surface through conduction and blood flow convection).

Skinfold thickness and the proximity of superficial nerves play a major role in the duration and location of application (Holcomb, 2005:61) and is a good indicator of an individual's tolerance for cold exposure (Wilmore *et al.,* 2008:271). In this regard Keatinge (1960:169) found a linear relation between the fall in rectal temperature during CWI and the thickness of subcutaneous fat. This is supported by Petrofsky and Laymon (2009:339) who found a greater temperature differential and slower heat flow response accompanied by a 73.2% significantly longer ($p < 0.01$) time constant in overweight subjects than in skinny subjects when during cold pack application (0°C for 20 min). Keatinge (1960:173) concluded that skinny men showed a higher metabolic rate in cold water than men with more subcutaneous fat. In another study, men with a lower percentage body fat (8.1–14.7%) showed a decrease in rectal temperature in a 75–123% shorter time than men with a higher percentage body fat (15–19%) (Xu *et al.*, 2007:82). One of the reasons for these differences is that a higher percentage fat will lead to a slower rate of cold transfer (due to the low thermal conductivity of fat) from the water to the deep tissues of the body (Wilmore *et al.*, 2008:271). For optimal deep tissue cooling subjects who reveal differences (0–10, 11-20, 21–30 and 31–40 mm) need approximately 12–15, 30, 40, and 60 minutes of required immersion duration respectively (Hawkins & Miller, 2012:3; Otte *et al.*, 2002:1504). A comparison between skinny and overweight subjects' responses to hot pack application (75°C for 20 min) also revealed that compared to overweight subjects, the skinny subjects showed half the change in muscle temperature ($p < 0.01$) as well as a time constraint (6.05 and 7.95 for each group respectively) (Petrofsky & Laymon, 2009:340). Thus it can be argued that the greater the body area to which the cold or warm is applied, the greater the amount of heat that will be transferred (Myrer *et al.*, 1994:321).

The possible effects of different immersion depths on the physiological responses of the body, is yet another factor that researchers have investigated. Nadler *et al.* (2004:396) stated that a local anaesthetic effect known as the cold-induced neuropraxia can occur as a result of a decrease in the temperature of skin and underlying tissue up to a depth of 2 to 4 cm. Researchers found that an increase in water immersion depth from waist to mid-chest and then to neck level led to a significant increase ($p < 0.05$) in sodium and potassium excretion rate in nine normal males (aged between 18–42 years) (Epstein *et al.*, 1974:563). Another study regarding the effect of immersion to either knee, hip or shoulder level in eight men (age: 24.8 years), revealed that heat flow responses were significantly smaller ($p < 0.05$) in the forearm site when subjects were immersed to shoulder or knee level compared to hip level in either 15°C or 25°C water (Lee *et al.*, 1997:1526). Additionally, heat flow was higher at the thigh site compared to forearm site when subjects were immersed to hip level, and heat flow at the calf site was higher than at the chest site with immersion at shoulder level. Furthermore, the metabolic responses were significantly higher ($p < 0.05$) when subjects were immersed to shoulder level than at knee or hip level (Lee *et al.*, 1997:1526). Differences in metabolic responses due to different immersion depths can possibly be attributed to an increase in circulating blood to a specific area (Epstein *et al.*, 1974:565). On the other hand, high blood circulation is the result of fluid that was distributed from the interstitial to the plasma compartment due to a higher hydrostatic pressure at higher immersion depths (Epstein *et al.*, 1974:565).

4. HYDROTHERAPY INTERVENTIONS

4.1. Cold water immersion (CWI)

Cryotherapy, also known as cold water immersion (CWI), is defined as "the therapeutic application of any substance to the body in order to remove heat, and cause a decrease in tissue temperature" (Nadler *et al.*, 2004:395). This is commonly used after the occurrence of acute musculoskeletal injuries to induce vasoconstriction and enhance recovery (Pournot *et al.*, 2011:1288). CWI induces both local (site of application) and distant (level of the spinal cord via neurologic and vascular mechanisms) effects (Nadler *et al.*, 2004:396). Researchers agree that the application of ice or CWI decreases skin, subcutaneous and muscle temperature, which in turn causes a decrease in tissue temperature (Cochrane, 2004:27; Sellwood *et al.*, 2007:392). The decrease in tissue temperature will then lead to the stimulation of the cutaneous receptors which will cause the sympathetic fibres to constrict and the metabolism and production of metabolites to slow down (Cochrane, 2004:27; Sellwood *et al.*, 2007:392).

It is postulated that a decrease in the metabolic demands of the injured tissue (Hawkins & Miller, 2012:1) will lead to a decrease in inflammation, pain and muscle spasm through the suppression of the monosynaptic stretch reflex (Cleak & Eston, 1992:334). As water temperature decreases, heart rate will reduce, which in turn will decrease cardiac output and arterial blood pressure and increase peripheral resistance (Śråmek *et al.*, 2000:440; Weston *et al.*, 1987:614). Reduced permeability of cellular, lymphatic and capillary vessels due to localized vasoconstriction will reduce fluid diffusion into the interstitial space (Weston *et al.*, 1987:614). This reduction in fluid diffusion can assist in reducing acute inflammation from muscle damage; which will result in reduced pain, swelling, oedema, acute trauma and the loss of force generation, all of which are associated with inflammation (Douris *et al.*, 2003:509; Nadler *et al.*, 2004:395; Rowsell *et al.*, 2009:572). Hydrostatic pressure, which is associated with CWI, may also assist in reducing early onset of swelling and inflammation due to muscular and vascular compression (Cochrane, 2004:27). Table 2 provides a brief summary of the CWI interventions that have been used in CWI therapy, detailing the effects on various haematological and performance components over a diverse population.

TABLE 2: Descriptions of studies regarding the effects of CWI on certain physiological and performance components.

Authors, date and title of publication	**Number, gender and age (years) of subjects**	**Intervention program**	**Results**
Ascensão *et al.* (2011) Effects of cold water immersion on the recovery of physical performance and muscle damage following a one-off soccer match.	20 Males 18.3 ± 0.8	To determine the effects of: • **Experimental group:** Immersion of the lower limbs up to the iliac crest for 10 min at a water temperature of 10°C. • **Control group:** Immersion of the lower limbs up to the iliac crest for 10 min at a water temperature of 35°C after: A once-off match over 14 days on: Perceived muscle soreness (PMS), Countermovement jump (CMJ), conventional squat jump, 20 m Sprint ability, maximal isometric quadriceps strength, Creatine Kinase (CK), Myoglobin and C-reactive protein before, at 30 min, 24 and 48-hour post-match playing.	CWI and PAR = ↓ CMJ * CWI *vs.* PAR = Smaller ↑ haematological variables at 24 and 48 hours. CWI = ↓ Peak Quadriceps strength at 48 hours. CWI = ↑ Peak Quadriceps strength at 24 hours. CWI = ↓ PMS at 24 hours.
Bahnert *et al.* (2013) Association between post-game recovery protocols, physical and perceived recovery, and performance in elite Australian Football League players.	45 Males 23.3 ± 4.2	To determine the effects of: • **Experimental group:** Immersion up to the hip in water at a temperature of 6–11°C for 8 min within 10–20 min post-game on: Physical test performances (five-repeated CMJ using a timing mat), a questionnaire-derived perception of recovery (fatigue, recovery, muscle soreness, stress levels, sleep quality and hardness of the previous training/game) and game performance ratings by the coach over the 23-game season.	CWI = Associated with perceptual recovery. CWI = No beneficial effect for recorded jumps CWI = Not associated with either the physical components or future-games.
Bailey *et al.* (2007) Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running.	20 Males 22.3 ± 3.3	To determine the effects of: • **Experimental group:** Immersion of the lower limbs at the level of the iliac crest for 10 min in water of 10°C. • **Control group:** Passive rest for 10 min. Before and after a 90-min intermittent shuttle run test at 75% of VO_{2max} as well as during the treatment over 7 days on: PMS (visual analogue scale), heart rate (HR) and core body temperature, maximal voluntary contraction (MVC) of the knee extensors and flexors, vertical jump height and sprint ability, blood analysis (plasma volume, CK and myoglobin concentrations) at 1, 24, 48 and 168-hours post-exercising.	CWI *vs.* PAR = ↓ PMS at 1, 24 and 48 hours * CWI *vs.* PAR = ↓ decrements in isometric MVC of the knee flexors at 24 and 48 hours. CWI = ↓ Myoglobin at 1 hour. CWI = ↔ CK response.

CMJ = Countermovement Jump; CK = Creatine Kinase; PMS = Perceived Muscle Soreness; HR = Heart Rate; MVC = Maximal Voluntary Contraction;
* = p ≤0.05; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 2 (cont.): Descriptions of studies regarding the effects of CWI on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Brophy-Williams *et al.* (2011) Effect of immediate and delayed cold water immersion after a high intensity exercise session on subsequent run performance.	8 Males 20.9 ± 1.2	To determine the effect of: • **Experimental group 1:** Immersion up to the mid-sternum in water at 15°C for 15 min immediately post-exercising. • **Experimental group 2:** Immersion up to the mid-sternum in water at 15°C for 15 min, 3 h post-exercising. • **Control group:** Seated for 15 min in laboratory conditions after: A high-intensity-interval-session consisting of eight 3-min intervals, done at 90% VO_{2max} velocity over a 24-h period on: PMS, Intermittent Yo-Yo test, HR, C-reactive protein and BLa^- after the 4th and 8th interval were completed, immediately and 3 h after the high-intensity-interval-session.	CWI *vs.* PAR = ↑ Shuttles completed. * CWI *vs.* PAR = ↑ Difference in the next day intermittent Yo-Yo test. ** CWI *vs.* PAR = ↔ PMS, BLa^- or HR. CWI *vs.* PAR = ↑ Ratings of perceived recovery. *
Corbett *et al.* (2012) Water immersion as a recovery aid from intermittent shuttle running exercise	40 Males 20 ± 2	To determine the effects of: • **Experimental group:** Immersion up to umbilicus in water at 12°C for 12 min. • **Control group:** Treadmill walking for 12 min at 5 km/h. After four sub-maximal treadmill exercise stages of 4-min duration followed by an increased gradient on: PMS, MVC of the knee extensors and flexors, CK and myoglobin.	CWI & PAR = ↔ PMS, MVC, CK and myoglobin.
Crampton *et al.* (2013) Cycling time to failure is better maintained by cold than contrast or thermoneutral lower-body water immersion in normothermia.	9 Males 30 ± 3	To determine the effects of: • **Experimental group:** Immersion up to the hip in water of 15°C for 30 min. • **Control group:** Active cycling at 40% VO_2 peak for 30 min. Within 5 min after a 5 min cycling at a workload of 50% VO_2 peak, followed by a 5-min at 60% and 80% over a 8-week period over four trials separated by 7 days on: Cycling performance, core temperature, BLa^- and HR.	CWI *vs.* contrast water therapy (CWT) = ↓ cycling performance. * CWI *vs.* CWT = ↓ Core temperature. CWI *vs.* active = ↑ BLa^- value. ** CWI = ↓ HR responses for the initial 10 min.

BLa^- = Blood lactate; CK = Creatine Kinase; CWI = Cold Water Immersion; CWT = Contrast Water Therapy; HR = Heart Rate; MVC = Maximal Voluntary Contraction; PAR = Passive Recovery; PMS = Perceived Muscle Soreness; VO_2max = Maximal Oxygen Uptake;
* = $p \leq 0.05$; ** = $p > 0.05$; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 2 (cont.): Descriptions of studies regarding the effects of CWI on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Delextrat *et al.* (2013) Effects of sports massage and intermittent cold-water immersion on recovery from matches by basketball players.	8 Males 23 ± 3 8 Females 22 ± 2	To determine the effects of: • **Experimental group:** Immersion up to iliac crest consisting of five 2-min immersions at 11°C, separated by a 2-min rest in ambient air. • **Control group:** Passive rest for 30 min ambient temperatures of 20°C. Within 5 min after the match on: Repeated sprint ability (RSA), CMJ, Perception of fatigue and PMS.	CWI = ↓ perception of fatigue in the legs. * CWI = ↔ RSA. CWI = ↑ CMJ and perceptual measures.
De Nardi *et al.* (2011) Effects of cold-water immersion and contrast-water therapy after training in young soccer players	18 Males 15.5 ± 1.0	To determine the effects of: • **Experimental group:** Immersion in water at 15°C up to the iliac spine level for 8 min. • **Control group:** Passive rest in the shade for 8 min. After 140 min training comprising of a wide range of soccer-specific exercises over 4-days on: CK, CMJ, 12 x 20 m RSA, 5-min steady-state submaximal running at 12 km.h^{-1}, haemoglobin, leukocytes, platelets and reticulocytes, uric acid and haematocrit one day before (Monday) and one day after (Saturday) training.	CWI = ↔ in RSA. PAR= ↓ RSA. CWI *vs.* PAR = Smaller ↓ CMJ. CWI *vs.* PAR = Smaller ↑ CK. * CWI & PAR = ↔ leukocytes, haemoglobin and reticulocytes.
Douris *et al.* (2003) Recovery of maximal isometric grip strength following cold immersion.	16 Males 32 ± 6.3	To determine the effect of: • **Experimental group:** Immersion of the upper extremity up to 10 cm proximal to the elbow in water at a temperature of 10°C for 5, 10, 15, and 20 min over 4 consecutive days on: Isometric grip strength measured immediately, 5, 10 and 15 min post-immersion after the completion of three baseline isometric MVCs.	CWI = ↔ grip strength. CWI = ↔ Recovery of strength loss.
Elias *et al.* (2012) Effects of water immersion on post training recovery in Australian footballers.	14 Males 20.9 ± 3.3	To determine the effects of: • **Experimental group:** Immersion up to the xiphoid process in water at a temperature of 12°C for 14 min. • **Control group:** 14 min passive rest in a seated position over 3 weeks on: RSA, CMJ and squat jump, PMS and fatigue measured 1, 24 and 48-h post-training after a 60-min football-related training session.	CWI = ↓ PMS and fatigue at 1 hour. CWI = ↑ CMJ and squat jump at 48 hours. CWI = Restored RSA at 24 hours and near base-line at 48 hours.

CK = Creatine Kinase; CMJ = Countermovement Jump; CWI = Cold Water Immersion; MVC = Maximal Voluntary Contraction; PAR = Passive Recovery; PMS = Perceived Muscle Soreness; RSA = Repeated Sprint Ability; * = p ≤0.05; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 2 (cont.): Descriptions of studies regarding the effects of CWI on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Elias *et al.* (2013) Effectiveness of water immersion on postmatch recovery in elite professional footballers.	24 Males 19.9 ± 2.8	To determine the effects of: • **Experimental group:** Immersion up to the xiphoid process in water at a temperature of 12°C for 14 min. • **Control group:** 14 min passive rest in a seated position within 12 min after the match on: Static jump, CMJ, RSA, PMS and perceived fatigue immediately, 1, 24 and 48-h post-match-playing.	CWI *vs.* PAR = ↓ PMS and fatigue ratings. CWI *vs.* PAR = ↑ alleviation at 1, 24 and 48 hours. CWI *vs.* PAR = ↑ all jump measures and restored static jump at 48 hours. CWI *vs.* PAR = Lower ↓ in RSA.
Gordon *et al.* (2003) Direct and indirect methods for determining plasma volume during thermoneutral and cold-water immersion.	7 Males 27.6 ± 9.2	To determine the effect of: • **Experimental group:** Immersion in water at 18.6°C for 60 min up to the third intercostal space, with the arms placed outside of the water on a tray at shoulder height. • **Control group:** Air control at 21.2°C over 42 days separated by 3 interventions of 14 days on: Plasma volume by measuring haematocrit and haemoglobin indirectly at 45 min of immersion and directly at 60 min of immersion as well as baseline.	CWI = ↓ rectal temperature decreased. * CWI = ↑ cardiac frequency. CWI = ↓ Plasma volume at 0 hours. * Researchers concluded that the indirect method underestimates the relative plasma volume changes by 52%.
Halson *et al.* (2008) Physiological responses to cold water immersion following cycling in the heat.	11 Males 23.8 ± 1.6	To determine the effect of: • **Experimental group:** Three cycles of immersion in water of 11.5°C to the level of the mesosternal for 60 sec, separated by 120 sec of seated rest, completing 9 min. • **Control group:** Seated passively for the duration of 9 min. After a 40-min cycling session on: HR, rectal and skin body temperature, BLa^-, glucose, pH, chloride, Na^+, HCO_3, K^+, PO_2 and PCO_2 before and after each CWI exposure. Testosterone, cortisol, growth hormone, prolactin, adrenaline, noradrenaline, CK, C-reactive protein were measured during and at 20 and 40 min post-exercising.	CWI *vs.* PAR = ↓ HR and skin temperature *

BLa^- = Blood lactate; CK = Creatine Kinase; CMJ = Countermovement Jump; CWI = Cold Water Immersion; HCO_3 = Bicarbonate; HR = Heart Rate; K^+ = Sodium; Na^+ = Potassium; PMS = Perceived Muscle Soreness, PCO_2 = Partial Carbon dioxide; PO_2 = Partial Oxygen; RSA = Repeated Sprint Ability;
* = p ≤0.05; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 2 (cont.): Descriptions of studies regarding the effects of CWI on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Howatson *et al.* (2009) The influence of cold water immersions on adaptation following a single bout of damaging exercise.	16 Males 23 ± 3	To determine the effect of: • **Experimental group:** Immersion for 12 min up to the iliac crest in water at 15°C. • **Control group:** Seated for 12 min passively. After a plyometric exercises comprising of drop jumps over 3 weeks on: CK, MVC, DOMS, knee-flexion range of movement, swelling (thigh circumference) before CWI treatment and at 1, 24, 48 and 72-h post-exercising.	CWI & PAR = ↑ Time effect in CK, MVC, DOMS and thigh circumference. * CWI & PAR = ↓ MVC at 0 hours, but recovered to 93% at 96 hours.
Ingram *et al.* (2009) Effect of water immersion methods on post-exercise recovery from simulated team sport exercise.	11 Males 27.5 ± 6	To determine the effect of: • **Experimental group:** Two 5-min immersions in water at 10°C separated with 2.5 min sitting upright at room temperature at 22°C. • **Control group:** Sitting quietly for 15 min. After 10 m x 20 m repeated sprints, 3 MVCs of the quadriceps, hamstrings and hip flexor muscles, 4 x 20 min quarters of intermittent running, separated by a 5-min recovery period, and then level 7 of the 20-m shuttle run, continuing until complete exhaustion was experienced over 2 weeks on: PMS of the quadriceps (10-point Likert scale), CK levels, C-reactive protein (inflammation), haemoglobin and haematocrit blood levels (plasma volume) immediately before and after the tests and at 24 and 48-h post-exercising.	CWI *vs.* PAR = ↓ PMS at 24 hours. * CWI *vs.* PAR = Faster total sprint times CWI = ↓ Sprint times at 48 hours. * CWI & PAR = ↔ isometric strength measures. CWI *vs.* PAR = Smaller ↓ in strength loss. CWI *vs.* PAR = ↔ CK and C-reactive protein.
Jakeman *et al.* (2009) A single 10min bout of cold-water immersion therapy after strenuous plyometric exercise has no beneficial effect on recovery from the symptoms of exercise-induced muscle damage.	18 Females 19.9 ± 1.0	To determine the effect of: • **Experimental group:** A 10 min immersion in water at 10°C seated with the legs at 90° to the torso, with the water up to the superior iliac crest. • **Control group:** 10 min seated passively. After 10 sets of 10-CMJ over 7 days on: CK levels, concentric quadriceps muscle strength, PMS (10 cm visual analogue scale) at 1-, 24-, 48-, 72- and 98 h post-exercising.	CWI & PAR = ↔ PMS, CK and concentric muscle strength. *

CK = Creatine Kinase; CMJ = Countermovement Jump; CWI = Cold Water Immersion; DOMS = Delayed Onset Muscle Soreness; PAR= Passive Recovery;
PMS = Perceived Muscle Soreness; * = p ≤0.05; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 2 (cont.): Descriptions of studies regarding the effects of CWI on certain physiological and performance components.

Authors, date and title of publication	**Number, gender and age (years) of subjects**	**Intervention program**	**Results**
King & Duffield (2009) The effects of recovery interventions on consecutive days of intermittent sprint exercise.	10 Females 19.5 ± 1.5	To determine the effect of: • **Experimental group:** Immersion in water at 9.3°C up to the iliac crest for 5 min, followed by 2.5 min seated at room temperature, performed twice. • **Control group:** Seated passively in a designated area in a gymnasium. After a 4 x 15 min intermittent-sprint and an exercise circuit designed to mimic the duration and performance demands of netball over 20 days with each intervention consisting of 2 sessions separated by 24 h, and 4 interventions separated by 5 days on: 5 CMJ in 20 sec, 5 x 20 m RSA, 10 m sprint, BLa^-, pH, HCO_3, HR, rate of perceived exertion (RPE) and PMS (10-point Likert scale) pre- and post-exercise.	CWI *vs.* PAR = ↓ vertical jump and HCO_3. ¶ CWI = ↔ 10 m sprint, pH and HR. CWI = ↓ Skin temperature and PMS at 24 hours. *
Montgomery *et al.* (2008) The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball.	29 Males 19.1 ± 2.1	To determine the effect of: • **Experimental group:** Immersion up to the mesosternal level for 5 x 1 min, separated by 2 min, at water temperatures of 11°C. • **Control group:** Completing 10 stretches twice for 15 sec. After a basketball tournament on: PMS (visual analogue scale), general fatigue, 20 m acceleration, basketball line-drill, Yo-Yo Level 1 intermittent recovery test, vertical jump, Basketball-specific agility test, mid-thigh girth, mid-calf girth and sit-and-reach test.	CWI = ↑ line-drill ability and velocity maintenance, ↓ 20-m acceleration test, agility and vertical jump height. CWI *vs.* PAR = ↑ maintenance in velocity and fatigue, and decrement in agility CWI *vs.* PAR = ↓ decrements in vertical jump and thigh girth distension and PMS CWI and PAR = ↓ sit-and-reach test.
Peiffer *et al.* (2009) Effect of cold water immersion after exercise in the heat on muscle function, body temperatures, and vessel diameter.	10 Males 27 ± 7	To determine the effect of: • **Experimental group:** Immersion up to the mid-sternal level for 5 min at a water temperature of 14°C. • **Control group:** Seated passively for 20 min. After a 90-min cycling session at 80% of the VO_2 recorded at the 2nd ventilatory threshold followed by a 16.1 km time trial on: MVC torque (knee extensors) and femoral venous diameters before and at 0, 45 and 90 min after the time trial.	CWI *vs.* PAR = ↔ 90 min cycle session, total work in the 16.1 km time trial, MVC of the knee extensors or flexors or skin- and rectal temperature. CWI = ↓ skin temperatures and MVC from 25-90 min and 45 and 90 min after the time trial.

BLa^- = Blood Lactate; CMJ = Countermovement Jump; CWI = Cold Water Immersion; HCO_3= Bicarbonate; HR = Heart rate; PMS = Perceived Muscle Soreness;
MVC = Maximal Voluntary Contraction; PAR = Passive Recovery; RPE = Rate of Perceived Exertion; RSA = Repeated Sprint Ability; VO_2 = Oxygen Uptake;
* = $p \leq 0.05$; ¶ = $d \geq 0.8$; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 2 (cont.): Descriptions of studies regarding the effects of CWI on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Peiffer *et al.* (2010) Effect of a 5-min cold-water immersion recovery on exercise performance in the heat.	10 Males 35 ± 7	To determine the effect of: • **Experimental group:** Immersion up to the mid-sternal level for 5 min at a water temperature of 14°C. • **Control group:** Seated passively for 15 min. In between two sessions of 25-min constant pace cycling on the Veletron cycle ergometer followed by a 4 km time trial in hot conditions on: Rectal temperature, RPE, VO_2, cycling economy, cycling cadence, cycling time and power output at baseline and after each time trial.	CWI *vs.* PAR = ↓ rectal temperature. * CWI *vs.* PAR = ↑ cycling cadence. * CWI *vs.* PAR = ↓ Average completion time and RPE during the 2nd test. CWI and PAR = ↑ time-trial. CWI and PAR = ↓ average power output from the 1st to 2nd test.
Pointon & Duffield (2012) Cold water immersion recovery after simulated collision sport exercise.	10 Males 21.0 ± 1.7	To determine the effect of: • **Experimental group 1:** Two cycles of immersion in water for 9 min at 9.2°C, 1 min seated at room air temperature, tackled during training. • **Control group 1:** Seated passively for 20 min, tackled during training. • **Control group 2:** Seated passively for 20 min, not tackled during training. Within 10 min after intermittent sprint exercise test over 3 testing sessions separated by 7 days on: Neuromuscular function (Voluntary activation, Potentiated twitch torque, rate of torque development and contraction duration), BLa^-, pH, HCO_3, RPE, and Sprint time at 0, 2 and 24 h post-exercising.	PAR = ↑ distance coverage. * CWI *vs.* PAR = ↓ mean sprint time. * CWI *vs.* PAR = ↑ MVC and maximum contraction. * CWI *vs.* PAR = ↓ pH and HCO_3. *
Pournot *et al.* (2011) Short term effects of various water immersions on recovery from exhaustive intermittent exercise.	41 Males 21.5 ± 4.6	To determine the effect of: • **Experimental group:** Immersion up to the iliac crest for 15 min at 10°C. • **Control group:** Seated for 15 min passively. After an intermittent anaerobic fatiguing exercise consisting of two bouts of 10 min, separated by 10 min rest over a 2 day period on: MVC (knee extensors muscles), CMJ (standardized knee-bend), CK, lactate dehydrogenase, PMS (visual analogue scale) prior to, 0, 1 and 24 h post-training.	CWI = ↓ suppressed performance state in MVC and CMJ. PAR = ↑ CK. * CWI and PAR = ↔ Leukocyte count values. ** CWI and PAR = ↑ DOMS at 24 hours. **

BLa^- = Blood Lactate; CK = Creatine Kinase; CMJ = Countermovement Jump; CWI = Cold Water Immersion; DOMS = Delayed Onset Muscle Soreness; HCO_3 = Bicarbonate; MVC = Maximal Voluntary Contraction; PAR = Passive Recovery; PMS = Perceived Muscle Soreness; RPE = Rate of Perceived Exertion; RSA = Repeated Sprint Ability; VO_2 = Oxygen Uptake; * = $p \leq 0.05$; ** = $p > 0.05$; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 2 (cont.): Descriptions of studies regarding the effects of CWI on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Rowsell *et al.* (2009) Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players.	20 Males 15.9 ± 0.6	To determine the effect of: • **Experimental group:** Five cycles of 60 sec immersions in water of 10°C, separated with a 60 sec period on a chair. • **Control group:** Thermoneutral water immersion of 5 cycles of 60 sec immersions, separated with a 60 sec period on a chair. Within 20 min after each match over 4 days on: Maximum CMJ, 12 x 20 m RSA, 5 min shuttle running (pre-set speed), perceived recovery, interleukin-Ib 6, IL-6, myoglobin, fatty acid binding protein, lactate dehydrogenase and CK after 20 min and 90 min before and 22 h after each match.	CWI and PAR = ↔ CMJ **, RSA *, CK * and lactate dehydrogenase *. CWI = ↓ PMS and general fatigue *
Sellwood *et al.* (2007) Ice water immersion and delayed onset muscle soreness; a randomised controlled trail.	11 Males 29 Females 21.4 ± 4.3	To determine the effect of: • **Experimental group:** Three immersion cycles up to the level of the anterior superior iliac spines in melting ice water at 5°C for 1 min, separated by 1 min out of the bath. • **Control group:** Three x 1 min immersion cycles up to anterior superior iliac spines in water of 24°C, with 1 min out of the bath. After an eccentric seated leg extension test (120% of 1 RM) over 3 days on: PMS (visual analogue scale), swelling by means of thigh circumference, one-legged hop for distance, maximal isometric quadriceps strength and Serum CK levels at baseline, 24, 48 and 72 h after exercising.	CWI *vs.* PAR = ↑ PMS at 24 hours. CWI and PAR = ↔ PMS, serum CK, thigh circumference, one legged hop or isometric strength.
Silva *et al.* (2011) Effect of water immersion on post-exercise recovery from a single bout of aerobic exercise.	4 Males 24.5 ± 3.7	To determine the effect of: • **Experimental group:** Immersion up to the height of the xiphoid process for 15 min in water of 18°C. • **Control group:** Seated passively for 15 min. After an eccentric knee extension test at 120% of 1RM, then running at 70% of VO_{2max} for 30 min over 28 days with 7 days intervals between tests on: HR, VO_2, BLa^- during exercise and recovery protocols.	CWI = ↔ BLa^- and post-exercise energy consumption. ** CWI = ↑ HR at the 12 minute.

BLa^- = Blood Lactate; CK = Creatine Kinase; CMJ = Countermovement Jump; CWI = Cold Water Immersion; HR = Heart Rate; PAR = Passive Recovery; PMS = Perceived Muscle Soreness; RM = Repetition Maximum; RSA = Repeated Sprint Ability; VO_2 = Oxygen Uptake; VO_{2max} = Maximal Oxygen Uptake; * = $p \leq 0.05$; ** = $p > 0.05$; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 2 (cont.): Descriptions of studies regarding the effects of CWI on certain physiological and performance components.

Authors, date and title of publication	**Number, gender and age (years) of subjects**	**Intervention program**	**Results**
Stanley *et al.* (2012) The effect of post exercise hydrotherapy on subsequent exercise performance and HR variability.	18 Males 27 ± 7	To determine the effect of: • **Experimental group:** Immersion of the body excluding the head and neck for 5 min at 14.2°C, then towelled dry, remain seated for final 5 min. • **Control group:** Seated passively for 10 min. After a 60 min high-intensity training session on cycling ergometers, comprising of a warm-up, 40 min intervals and a cool-down on: HR variability, performance time trial, HR and power output, Perception of recovery, perceived level of general fatigue, mental recovery, PMS and physical recovery 20 min post-exercising.	CWI *vs.* PAR = ↓ HR, PMS and general fatigue. CWI *vs.* PAR = ↑ Power output. CWI and PAR = ↔ Power output between all trials.
Stocks *et al.* (2004) Effects of immersion water temperature on whole-body fluid distribution in humans.	7 Males 24.7 ± 8.7	To determine the effect of: • **Experimental group:** Immersion for 60 min in water at 18.1°C up to the fourth intercostal space, resting both arms on a tray above water level throughout immersion. • **Control group:** No control group as the subjects' resting, pre-immersion body fluids were used as the frame of reference over 30 days on: Base-line body-fluid compartment measured in seated and resting subjects, in a controlled position for at least 4 h, and immediately prior to, and at 59 min of immersion the following blood samples were taken: haematocrit and haemoglobin to determine plasma volume, osmolality, Na$^+$, K$^+$, total protein and aldosterone.	CWI = ↓ terminal esophageal, skin temperatures and intracellular fluid. * CWI = ↑ divergence in plasma volume. CWI = ↓ intracellular fluid. CWI = ↑ Na$^+$ at 60 min. *
Strejcová & Konopková (2012) The effect of active recovery, cold water immersion and passive recovery on subsequent knee extension and flexion strength.	14 Males 26.6 ± 4.4	To determine the effect of: • **Experimental group:** Immersion up to the hips at a water temperature of 13°C for 3 x 2.5 min with 2 min out of the water, repeated twice. • **Control group:** Seated for 15 min at room temperature of 22°C. After three isokinetic knee strength (extension and flexion) trials in one day with 15 min recovery between trials on: Maximal and average HR, knee extension and flexion for: peak torque; total work and average power.	CWI and PAR = ↑ Differences in HR during the interventions. * CWI *vs.* PAR and active = Active recovery showed to be superior to PAR or CWI.

CWI = Cold Water Immersion; HR = Heart Rate; K$^+$ = Sodium; Na$^+$ = Potassium; PAR = Passive Recovery; PMS = Perceived Muscle Soreness;
* = p ≤0.05; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 2 (cont.): Descriptions of studies regarding the effects of CWI on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Tikuisis *et al.* (2002) Shivering endurance and fatigue during cold water immersion in humans.	11 Females 24.4 ± 6.3	To determine the effect of: • **Experimental group:** Immersion up to the neck level at 18°C for 90 min on: Rectal body temperature, respiratory gases using a semi-automated metabolic cart system, Muscle samples from the right quadriceps femoris lateralis at 15 min before and 5 min after immersion to determine glucose units, venous blood samples were drawn before and after 5, 30, 60 and 90 min of immersion to determine glucose, BLa^-, haematocrit, and haemoglobin.	CWI = ↑ Blood plasma glucose levels CWI = ↓ Average rate of oxygen consumption. * CWI = ↓ Esophageal and skin temperatures at the last 90 min. *
Vaile *et al.* (2008a) Effect of hydrotherapy on the signs and symptoms of delayed onset muscle soreness.	38 Males Age not Reported	To determine the effect of: • **Experimental group:** Immersion of the entire body (excluding the head and neck) in water of 15°C for 14 min. • **Control group:** Seated with minimal movement for 14 min. After various eccentric bi-lateral leg press contractions over 8 months on: Isometric squat force- and jump performance, CK, myoglobin, Interleukin-6, lactate dehydrogenase, thigh circumference and PMS at 0, 24, 48 and 72 h.	CWI and PAR = ↔ isometric squat ** CWI *vs.* PAR = ↓ change in isometric squat and weighted squat jump. CWI *vs.* PAR = ↓ thigh circumference at 24, 48 and 72 hours. * CWI *vs.* PAR = ↓ CK at 24 and 48 hours. *
Vaile *et al.* (2008b) Effect of hydrotherapy on recovery from fatigue.	12 Males 32.2 ± 4.3	To determine the effect of: • **Experimental group:** Immersion of the entire body (excluding the head and neck) in water of 15°C for 14 min. • **Control group:** Seated with minimal movement for 14 min. After 3 x 3 sec sprints, a 9-min effort consisting of 2 x 2 min and a 5-min time trial over a 5-day period on four separate occasions separated by nine days on: Core temperature, HR, RPE, time trial- and sprint performance.	CWI *vs.* PAR = ↑ Maintenance of average sprint power and time trial performance. * CWI *vs.* PAR = ↑ differences rectal temperature. * CWI *vs.* PAR = ↑ HR on day 4 and 5. ‡ CWI and PAR = ↔ RPE.

BLa^- = Blood Lactate; CK = Creatine Kinase; CWI = Cold Water Immersion; HR = Heart Rate; PAR = Passive Recovery; PMS = Perceived Muscle Soreness; RPE = Rate of Perceived Exertion; * = $p \leq 0.05$; ** = $p > 0.05$; ‡ = $d \geq 0.5$; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 2 (cont.): Descriptions of studies regarding the effects of CWI on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Webb *et al.* (2013) The relative efficacy of three recovery modalities after professional rugby league matches.	21 Males 23.5 ± 2.6	To determine the effect of: • **Experimental group:** Immersion of the lower body up to the anterior superior iliac spine in water of 10-12°C for 5 min. • **Control group:** Active recovery done on a cycle ergometer for 7 min. After 3 consecutive home games over a 6 week period on: CK, CMJ height, PMS and contact fatigue.	CWI = ↑ jump height at 18-42 hours post-match. CWI *vs.* Active = ↓ at 1-18 hours post-match. CWI = Possible beneficial effects on CK at 18-42 hours post-match.
Yamane *et al.* (2006) Post-exercise leg and forearm flexor muscle cooling in humans attenuates endurance and resistance training effects on muscle performance and on circulatory adaptation.	Not Reported	To determine the effect of: • **Experimental group 1:** Water immersion of the leg so that the thigh and lower leg is immersed, but the foot tip kept out of water to avoid cold pain at 5°C for 20 min. • **Experimental group 2:** Immersion of the elbow joint into the water at 10°C for 20 min, so that the elbow joint to the wrist was immersed, with the hand kept out of water to avoid cold pain. Before and after 25 min of cycling at 70% VO_{2max}, handgrip exercises at 70-80% of maximum strength, 3-4 times a week for 4-6 weeks on: Two-leg incremental exercise, maximal isometric contraction of the forearm flexor muscles, VO_2 and CO_2 3 days before and after training.	CWI *vs.* PAR = ↑femoral diameter. * CWI *vs.* PAR = ↑ Maximal isometric muscle strength of the flexor muscles. *

CK = Creatine Kinase; CMJ = Countermovement Jump; CO_2 = Carbon Dioxide; CWI = Cold Water Immersion; PAR = Passive Recovery;
PMS = Perceived Muscle Soreness; VO_2 = Oxygen Uptake; $VO_{2\,max}$ = Maximal Oxygen Uptake; * = $p \leq 0.05$; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

4.1.1.Results from CWI interventions

Table 2 indicates that 14 studies (Ascensão *et al.*, 2011; Bailey *et al.*, 2007; Brophy-Williams *et al.*, 2011; Corbett *et al.*, 2012; Jakeman *et al.*, 2009; King & Duffield, 2009; Pointon & Duffield, 2012; Pournot *et al.*, 2011; Rowsell *et al.* 2009; Sellwood *et al.* 2007.; Stanley *et al.*, 2012; Vaile *et al.*, 2008a; Vaile *et al.*, 2008b; Webb *et al.*, 2013) have evaluated the effect of CWI on various (physical, physiological and psychological) performance components of their participants. Eight studies (Crampton *et al.*, 2013; De Nardi *et al.*, 2011; Howatson *et al.*, 2009; Peiffer *et al.*, 2009; Peiffer *et al.*, 2010; Silva *et al.*, 2011; Strejcová & Konopková, 2012; Yamane *et al.*, 2006) evaluated physical as well as physiological parameters with the latter variables tested separately in only four studies (Gordon *et al.*, 2003; Halson *et al.*, 2008; Stocks *et al.*, 2004; Tikuisis *et al.*, 2002). Interestingly, five studies (Bahnert *et al.*, 2013; Delextrat *et al.*, 2013; Elias *et al.*, 2012; Elias *et al.*, 2013; Montgomery *et al.*, 2008) also evaluated the psychological aspect of recovery together with the physical components whereas only one study (Douris *et al.*, 2003) could be found that only evaluated the physical component in participants.

CWI may also induce various physiological responses affecting the subsequent exercise performance in a negative manner (Stanley *et al.*, 2014:148). This was seen with researchers reporting no significant ($p < 0.05$) improvement in vertical jump height in twenty healthy men (age = 22.3 years) after the application of CWI following a prolonged intermittent shuttle run (Bailey *et al.*, 2007:1166). In addition, Ferretti *et al.* (1992:113) reported a 27% statistically significant decrease ($p < 0.01$) in jump height when CWI was applied before and after a series of jumps on a force platform in six sedentary male subjects (age 31 years). The same negative trend was seen in two studies reporting a decrease in CMJ following CWI recovery (Ascensão *et al.*, 2011; King & Duffield, 2009). Additionally, studies reported a decrease in either MVC (Ascensão *et al.*, 2011; Howatson *et al.*, 2009; Peiffer *et al.*, 2009), agility (Montgomery *et al.*, 2008), sprint times (Ingram *et al.*, 2009) or plasma volume (Gordon *et al.*, 2003; Stocks *et al.*, 2004) with one study (Sellwood *et al.*, 2007) reporting an increase in pain experienced at 24 hours. Banfi *et al.* (2009:191) point out that the application of cryotherapy in the form of cold air on ten male athletes (age = 26 years) caused a statistically significant decrease ($p < 0.01$) in blood haemoglobin levels with no significant change in haemotocrit levels.

Various studies indicated no difference from baseline values in either CMJ (Bahnert *et al.*, 2013; Rowsell *et al.*,2009), sprint ability (Ascensão *et al.*, 2011; Delextrat *et al.*, 2013; De Nardi *et al.*, 2011; King & Duffield, 2009; Rowsell *et al.*, 2009), MVC of the knee extensors or flexors (Corbett *et al.*, 2012; Ingram *et al.*, 2009; Jakeman *et al.*, 2009; Vaile *et al.*, 2008a) or perception of leg soreness (Brophy-Williams *et al.*, 2011; Corbett *et al.*, 2012; Jakeman *et al.*, 2009). Also, no differences were reported in various physiological components, including CK (Bailey *et al.*, 2007; Corbett *et al.*, 2012; Ingram *et al.*, 2009; Jakeman *et al.*, 2009; Rowsell *et al.*, 2009; Sellwood *et al.*, 2007), BLa$^-$ (Brophy-Williams *et al.*,2011; Silva *et al.*, 2011), heart rate (Brophy-Williams *et al.*, 2011) and haemoglobin (De Nardi *et al.*, 2011). Furthermore, no significant differences ($p > 0.05$) were found in pH, bicarbonate (HCO_3), sodium (Na^+), potassium (K^+) or the partial pressure of carbon dioxide (PCO_2) in endurance cyclists after a 40-min cycle session in the heat (Halson *et al.*, 2008:337).

Positive results were reported with either an improvement in MVC (Ascensão *et al.*, 2011; Yamane *et al.*, 2006), CMJ (Delextrat *et al.*, Elias *et al.*, 2012; Webb *et al.*, 2013) or line drill and velocity (Montgomery *et al.*, 2008). In addition, players reported a lower perception of muscle soreness (Ascensão *et al.*, 2011; Bailey *et al.*, 2007; Elias *et al.*, 2012; King & Duffield, 2009; Rowsell *et al.*, 2009) and perception of fatigue experienced in the legs (Delextrat *et al.*, 2013; Elias *et al.*, 2012 Rowsell *et al.*, 2009) following a bout of CWI. A study completed on male rugby players did, however, observe a significant enhancement ($p = 0.03$) in the immediate recovery of maximal voluntary knee-contraction strength after a simulating collision exercise (Pointon & Duffield, 2011:212).

In addition, CWI, compared to PAR, resulted in a smaller increase in CK levels (Ascensão *et al.*, 2011; De Nardi *et al.*, 2011; Vaile *et al.*, 2008a), a larger decrease in the perception of muscle soreness (Bailey *et al.*, 2007; Elias *et al.*, 2013; Ingram *et al.*, 2009; Montgomery *et al.*, 20008; Stanley *et al.*, 2012; Webb *et al.*, 2013) and lower ratings of fatigue experienced (Elias *et al.*, 2013; Stanley *et al.*, 2012). Furthermore, a more beneficial outcome was demonstrated by Brophy-Williams and associates (2011), Ingram and associates (2009) as well as Peiffer and associates (2010) who reported either an increase in the number of shuttles completed, faster sprint times or an increase in power output following CWI compared to the results presented after PAR. However, the latter study (Peiffer *et al.*, 2010) also conveyed a less favourable outcome as a result of CWI, since a slower completion time for the cycling time-trial test was observed when compared to the PAR-group's results. In addition to these negative results, Pointon and Duffield (2011) reported slower sprint times in males after a simulating collision sport exercise and Bailey and colleagues (2007), in turn, a larger decrease in MVC of the knee extensors and flexors in 20 males (age: 22.3 ± 3.3 years) after a 90-min intermittent shuttle-run test.

A study done by Pournot and colleagues (2011:1288) suggested that CWI is more effective in preventing the harmful effects of inflammation and initiating the restoration of maximal anaerobic performance than do CWT and PAR. A number of studies compared the effects of CWI and CWT. In this regard Elias *et al.* (2012:361) and Elias *et al.* (2013:249) concluded that CWI is more effective for the restoration of physical performance and psychometric perceptions than is CWT. They showed that CWI was more effective at attenuating the decline in sprint and squat jump performance as well as in restoring jump performance in all jump measures over a 48-h period (Elias *et al.,* 2013:249).

4.2. Contrast Water Therapy (CWT)

CWT has a long history of being used as a recovery aid by the sports medicine community (Higgins & Kaminski, 1998:336) and is commonly used in rheumatic conditions and regional pain syndrome (Nadler *et al.,* 2004:398). CWT is a combination of cold (CWI) and heat (thermotherapy) water modalities, usually alternating between immersion in warm and cold-water (Higgins & Kaminski, 1998:336; Myrer *et al.*, 1994:318). Thus CWT alternates between the phases of vasodilatation and vasoconstriction, which might lead to an immune response and result in a reduction of myocellular damage (Pournot *et al.*, 2011:1294). The theory behind CWT is to stimulate area-specific blood flow, increase blood lactate removal, reduce inflammation and oedema, provide relief from stiffness and pain (Wilcock *et al.*, 2006:760) as well as stimulate the central nervous system (Cochrane, 2004:27).

CWT protocols differ by range, timing, temperature and duration (Breger Stanton *et al.,* 2009:57), and is dependent on the following: if vasodilation (increased blood flow) is desired, the recovery modality should end with the application of heat (thermotherapy), whereas ending with cold immersion (CWI) will lead to an increased vasoconstriction (decreased blood flow) (Higgins & Kaminski, 1998:336). There is no evidence for recommending ending with either thermotherapy or CWI, although in the sub-acute phase of an injury, the treatment will typically conclude with cold application, whereas a more chronic condition may conclude with heat application (Higgins & Kaminski, 1998:336). Care should be taken when applying CWT as it may be similar to heat application causing inflammation (Wilcock *et al.,* 2006:760). A brief overview of different research studies will follow in Table 3, detailing the effects of CWT on various haematological and performance components over a diverse population.

TABLE 3: Descriptions of studies regarding the effects of CWT on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Bahnert *et al.* (2013) Association between post-game recovery protocols, physical and perceived recovery, and performance in elite Australian Football League players.	45 Males 23.3 ± 4.2	To determine the effect of: • **Experimental group:** Immersion up to the hip, alternating between a 1-min ice bath at 6–11°C and 2 min warm bath at 38°C completing 4 cycles, for 12 min. • **Control group:** None Within 10–20 min post-game over a 23-game season on: Five-repeated CMJ using a timing mat, perception of recovery (computer-based questionnaire) on 6 variables: fatigue, recovery, PMS, stress levels, sleep quality and hardness of the previous training/game and game performance ratings from the coach on a 0–4 scale.	CWT = Not associated with physical performance or next game performance.
Coffey *et al.* (2004) Effect of recovery modality on 4-hour repeated treadmill running performance and changes in physiological variables.	14 Males 26.4 ± 6.6	To determine the effect of: • **Experimental group:** Immersion of the lower body to the level of the anterior superior iliac spine in an upright position, alternating between 60 sec cold water (10°C) and 120 sec hot water (42°C) for 15 min, then 5 min seated rest. Beginning with cold water and ending with hot water. • **Control group:** Standing upright for 15 min confined within an 80 cm diameter circle, and then 5 min seated rest. After repeated performance at 120% and 90% of peak running speed on a treadmill to exhaustion on: HR, RPE recovery and BLa^- at rest, immediately, and 4, 8, 12, 16 and 20 min after the first treadmill runs, blood pH was measured at rest, 20 min after the first runs and immediately before the last pair of runs.	CWT *vs.* PAR = ↓ Predicted times to cover 5000 m on the treadmill. * CWT and PAR = ↔ BLa^- and rate of perceived exertion recovery. CWT *vs.* PAR = ↓ BLa^- and rate of perceived exertion recovery.

BLa^- = Blood Lactate; CMJ = Countermovement Jump; HR = Heart Rate; PAR = Passive Recovery; PMS = Perceived Muscle Soreness; RPE = Rate of Perceived Exertion; * = $p \leq 0.05$; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 3 (cont.): Descriptions of studies regarding the effects of CWI on certain physiological and performance components.

Authors, date and title of publication	**Number, gender and age (years) of subjects**	**Intervention program**	**Results**
Crampton *et al.* (2013) Cycling time to failure is better maintained by cold than contrast or thermoneutral lower-body water immersion in normothermia.	9 Males 30 ± 3	To determine the effects of: - **Experimental group:** Eleven immersion cycles up to the hip, alternating between cold water of 8°C for 2.5 min and warm water at 40°C. - **Control group:** Active (ACT) cycling at 40% VO_{2peak} for 30 min. After a 5-min cycle at a workload of 50% VO_{2peak}, followed by a 5 min at 60% and 80% over a 8-week period over four trials separated by 7 days on: Cycling performance, core temperature, BLa^- and HR.	CWT and control group = ↔ Cycling performance and BLa^-. * CWT = ↓ Cycling performance of exercise 2. * CWT = ↑ HR following every transition between baths, although HR tended to be larger when moving from warm to cold water.
Dawson *et al.* (2005) Effect of immediate post-game recovery procedures on muscle soreness, power and flexibility levels over the next 48 hours.	17 Males 24.2 ± 2.9	To determine the effect of: - **Experimental group:** Alternated immersions in a hot shower for 2 min at 45°C, and standing in icy water of 12°C for 1 min, repeating it until 5 hot and 4 cold exposures were completed. - **Control group:** Remained passive for 14 min. After a match on: PMS (7-point Likert scale), Flexibility using the sit-and-reach test, 6-sec cycle sprint measuring total work, power and time to peak power and maximum voluntary jump measured at baseline, 15 and 48 h post-game.	CWT and PAR = ↑ PMS. * CWT *vs.* PAR = ↔ PMS. PAR = ↓ vertical jump and 6-sec work and power scores.
De Nardi *et al.* (2011) Effects of cold-water immersion and contrast-water therapy after training in young soccer players.	18 Males 15.5 ± 1.0	To determine the effect of: - **Experimental group:** Alternated immersions of 2 min in cold- (15°C) and warm water (28°C) up to the iliac spine level for a period of 8 min. - **Control group:** Rested passively in the shade for 8 min. After 140 min training comprising of soccer-specific drills on: CK, CMJ, 12 x 20-m repeated sprints, 5-min steady-state submaximal running at 12 $km.h^{-1}$, haemoglobin, leukocytes, platelets and reticulocytes, uric acid and haematocrit before (Monday) and after (Saturday) the interventions.	CWT and PAR = ↔ RSA, leukocytes, haemoglobin or reticulocytes. ** CWT *vs.* PAR = Smaller ↓ CMJ. * CWT *vs.* PAR = Smaller ↑ CK. *

BLa^- = Blood Lactate; CK = Creatine Kinase; CMJ = Countermovement Jump; CWT = Contrast Water Therapy; HR = Heart Rate; PAR = Passive Recovery; PMS = Perceived Muscle Soreness; RSA = Repeated Sprint Ability; VO_{2peak} = Peak Oxygen Uptake; * = $p \leq 0.05$; ** = $p > 0.05$; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 3 (cont.): Descriptions of studies regarding the effects of CWT on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Elias *et al.* (2012) Effects of water immersion on post training recovery in Australian footballers.	14 Males 20.9 ± 3.3	To determine the effect of: • **Experimental group:** Seven immersion cycles up to the xiphoid process for 1 min cold water at 12°C and 1min warm water at 38°C for 14 min. • **Control group:** Seated passively for 14 min. After a 60-min training session consisting of a warm-up, skill development and small-sided games on: RSA, CMJ and squat jump, PMS and fatigue measured after 1, 24 and 48 h.	CWT = ↓ PMS and fatigued at 1 and 48 hours. CWT = Restored CMJ at 48 hours. CWT = Restored RSA times at 24 and 48 hours.
Elias *et al.* (2013) Effectiveness of water immersion on postmatch recovery in elite professional footballers.	24 Males 19.9 ± 2.8	To determine the effects of: • **Experimental group:** Seven immersion cycles up to the xiphoid process for 1 min cold water at 12°C and 1 min warm water at 38°C for 14 min. • **Control group:** 14-min passive rest in a seated position within 12 min after the match on: Static jump, CMJ, RSA, PMS and perceived fatigue at 0, 1, 24 and 48 h post-match-playing.	CWT *vs.* PAR = ↓ PMS and fatigue. CWT *vs.* PAR = Restoring jump performances after 24 and 48 hours.
French *et al.* (2008) The effects of contrast bathing and compression therapy on muscular performance.	26 Males 24.12 ± 3.2	To determine the effect of: • **Experimental group:** Alternating between cold (8–10°C) for 60 sec and hot (37–40°C) water immersions for 180 sec with legs outstretched with a water depth of 50 cm in, and completing four cold and three hot baths. • **Control group:** Subjects did not complete any post-exercising cool-down or stretching activities, nor did they receive any form of analgesic, holistic or prophylactic therapy. After a high-intensity exercise protocol on a plate-loaded Smith machine on: Mid-thigh and mid-calf limb girth, maximum static range of movement for six movements of the lower extremity, CMJ, sprint speed over 10 and 30 m, Whole-body strength using a 5 RM parallel back squat, PMS, CK and myoglobin concentrations at baseline, 1, 24 and 48 h post-recovery.	CWT *vs.* PAR = ↔ 30-m sprint speed and CK. ** CWT = ↓ CK at 24 and 48 hours. ¶ CWT = ↑ Myoglobin and mid-thigh girth at 1 hour post-recovery. * CWT and PAR = ↑ differences for CMJ. CWT and PAR = ↔ 10-m sprint times.

CK = Creatine Kinase; CMJ = Countermovement Jump; CWT = Contrast Water Therapy; PAR = Passive Recovery; PMS = Perceived Muscle Soreness; RM = Repetition Maximum; RSA = Repeated Sprint Ability; * = p ≤0.05; ** = p >0.05; ¶ = d ≥0.8; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 3 (cont.): Descriptions of studies regarding the effects of CWT on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Gill *et al.* (2006) Effectiveness of post-match recovery strategies in rugby players.	23 Males 25 ± 3	To determine the effect of: • **Experimental group:** Immersion up to the anterior superior iliac spine, alternating between 1 min in cold water at 8–10°C and 2 min in hot water at 40–42°C for 9 min. • **Control group:** Sat on a bench for 9 min. After a rugby match on: CK levels immediately after and at 36 and 84 hours post-match-playing.	CWT = 85% recovery in CK after 84 hours.
Hamlin (2007) The effect of contrast temperature water therapy on repeated sprint performance.	17 Males 3 Females 19 ± 1	To determine the effect of: • **Experimental group:** Three 1 min hip-height immersions in cold water of 8-10°C alternated with three 1 min hot water showers at 38°C. • **Control group:** Slow jogging for 6 min. Between two bouts of RSA: BLa^-, HR and 10 x RSA.	CWT = ↑ Mean time to complete the ten 40-m RSA. CWT = ↓ BLa^- and HR after the first bout of sprints. CWT and PAR = ↓ RSA.
Ingram *et al.* (2009) Effect of water immersion methods on post-exercise recovery from simulated team sport exercise.	11 Males 27.5 ± 6	To determine the effect of: • **Experimental group:** Alternating 2-min immersions in cold water at 10°C and warm water at 40°C, repeated 3 times, with a 30-sec changeover, for 15 min. • **Control group:** Sitting quietly for 15 min. After 10 m x 20 m and 3 MVCs of the quadriceps, hamstrings and hip flexor muscles, followed by 4 x 20-min quarters of intermittent running, separated with 5-min recovery period, finishing with level a 20-m shuttle run at level 7 until complete exhaustion was experienced on: PMS (10-point Likert scale of the quadriceps), CK levels, C-reactive protein for measuring inflammation, haemoglobin and haematocrit blood levels to determine changes in plasma volume measured immediately before and after the tests and at 24 and 48 h post-training.	CWT *vs.* PAR = ↓ PMS at 24 hours. * CWT and PAR = ↓ sprint times at 48 hours. * CWT and PAR = ↑ strength losses for leg extension and flexion at 48 hours. * CWT and PAR = ↔ CK and C-reactive protein.

BLa^- Blood Lactate; CK = Creatine Kinase; CWT = Contrast Water Therapy; HR = Heart Rate; PAR = Passive Recovery; PMS = Perceived Muscle Soreness; RSA = Repeated Sprint Ability; * = $p \leq 0.05$; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 3 (cont.): Descriptions of studies regarding the effects of CWT on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
King & Duffield (2009) The effects of recovery interventions on consecutive days of intermittent sprint exercise.	10 Females 19.5 ± 1.5	To determine the effect of: • **Experimental group:** Alternated immersions in cold (9.7°C) water for 1 min and warm (39.1°C) water for 2 min, repeated 4 times, completing 5 exposures. • **Control group:** Seated passively in a designated area in a gymnasium. After 4 x 15-min intermittent-sprint and netball- exercise circuit over a 20-day period. Each recovery intervention consisted of 2 sessions, separated by 24 h with 4 modalities separated with 5 days on: 5 x CMJ in 20 sec, 5 x 20 m RSA, 10 m sprint, Nude mass, BLa^-, pH, HCO_3, HR, Core body temperature, RPE and PMS pre- and post-exercise.	CWT *vs.* PAR = ↑ decrement for the 20-m sprint. ¶ CWT and PAR = ↔ HR. ** CWT = ↓ BLa^- and PMS at 24 hours. *
Morton (2007) Contrast water immersion hastens plasma lactate decrease after intense anaerobic exercise.	6 Males 5 Females 21.7 ± 1.1	To determine the effect of: • **Experimental group:** Alternated immersions up to the gluteal fold in hot (36°C) and cold (12°C) baths: Hot (9), cold (1), hot (4), cold (1), hot (4), cold (1), hot (4), cold (1), hot (4), cold (1), time in minutes. • **Control group:** Lying stationary for 30 min. After four successive 30-sec Wingate tests, separated by 30 sec relative rest periods cycling at level 2 over 3 occasions on: BLa^- at 5 min intervals for 30 min.	CWT *vs.* PAR = ↓ BLa^- over the 30 min.* Males *vs.* Females = ↔ BLa^-.
Pournot *et al.* (2011) Short term effects of various water immersions on recovery from exhaustive intermittent exercise.	41 Males 21.5 ± 4.6	To determine the effect of: • **Experimental group:** Five cycles up to the iliac crest for 15 min alternating in cold water at 10°C and warm water at 42°C for 90 sec. • **Control group:** Seated for 15 min passively. After two 10-min anaerobic fatiguing exercises, over a 2 day period on: MVC (knee extensors muscles), CMJ (standardized knee-bend), CK, lactate dehydrogenase, PMS (visual analogue scale) prior, 0, 1 and 24 h post training.	CWT and PAR = ↑ main effect for time change in performance measures. * CWT and PAR = ↑ lactate and leukocytes, neutrophils and monocytes at 1 hour. * CWT and PAR = ↑ DOMS at 24 hours. * CWT = ↓ suppressed performance in MVC and CMJ.

BLa^- = Blood Lactate; CK = Creatine Kinase; CMJ = Countermovement Jump; CWT = Contrast Water Therapy; DOMS = Delayed Onset Muscle Soreness; HCO_3 = Bicarbonate; HR = Heart Rate; MVC = Maximal Voluntary Contraction; PAR = Passive Recovery; PMS = Perceived Muscle Soreness; RPE = Rate of Perceived Exertion; * = $p \leq 0.05$; ** = $p > 0.05$; ¶ = $d \geq 0.8$; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 3 (cont.): Descriptions of studies regarding the effects of CWT on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Robey *et al.* (2009) Effect of postexercise recovery procedures following strenuous stair-climb running.	8 Males 20.2 ± 2.2 6 Females 21.1 ± 3.6	To determine the effect of: • **Experimental group:** Alternating between a hot shower (40°C) for 2 min and immersion in an ice bath (12°C) for 1 min up to the iliac crest for 15 min at 10°C, completing 5 cycles. • **Control group:** Seated for 15 min passively. After a stair-climb run on: CK, PMS (7-point Likert scale), rowing peak torque and rowing ergometer at 24, 48 and 72 h post-run.	CWT and PAR = ↔ CK, PMS or rowing peak torque. CWT *vs.* PAR = ↔ CK, PMS or rowing peak torque CWT *vs.* PAR = ↓ rowing ergometer at 72 hours post-run. **
Sayers *et al.* (2011) Effect of whole-body contrast-water therapy on recovery from intense exercise of short duration.	14 Males 17.5 ± 0.5	To determine the effect of: • **Experimental group:** 3 Cycles of immersions in water up to the jugular notch, exposed to a warm pool at 38°C for 3.5 min, followed by a cool pool at 15°C for 30 sec over 12 min. • **Control group:** Seated upright with legs outstretched for 12 min. After a 30 sec Wingate anaerobic test on: Wingate peak and average power and total work, HR, blood pressure, BLa^- and ratings of fatigue 0, 3 and 7 min post-exercise.	CWT and PAR = ↔ in any performances. CWT = ↓ power decline. * CWT = ↓ Rating of fatigue. * PAR = ↑ BLa^-.
Stanley *et al.* (2012) The effect of post exercise hydrotherapy on subsequent exercise performance and HR variability.	18 Males 27 ± 7	To determine the effect of: • **Experimental group:** Immersion of the body (excluding the head and neck) for 10 min alternating between cold water at 14.2°C for 1 min, and warm water at 35.5°C for 2 min, ending with 1 min cold, then towelled dry, completing 3 cycles. • **Control group:** Seated for 10 min passively. After a 60 min high intensity cycling session on cycling ergometers on: HR variability, performance time trial, HR and power output, Perception of recovery, PMS, perceived level of general fatigue and mental- and physical recovery.	CWT *vs.* PAR = ↔ HR. CWT *vs.* PAR = ↓ General fatigue and PMS. CWT *vs.* PAR = ↑ perception of physical recovery.

BLa^- = Blood Lactate; CK = Creatine Kinase; CWT = Contrast Water Therapy; HR = Heart Rate; PAR = Passive Recovery; PMS = Perceived Muscle Soreness;
* = $p \leq 0.05$; ** = $p > 0.05$; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 3 (cont.): Descriptions of studies regarding the effects of CWT on certain physiological and performance components.

Authors, date and title of publication	**Number, gender and age (years) of subjects**	**Intervention program**	**Results**
Vaile *et al.* (2008a) Effect of hydrotherapy on the signs and symptoms of delayed onset muscle soreness.	38 Males Not Reported	To determine the effect of: • **Experimental group:** Seven immersion cycles of the entire body (excluding the head and neck) for 1 min, alternating between cold water (15°C) and hot water (38°C) for a total of 14 min. • **Control group:** Seated with minimal movement for 14 min. After several eccentric bi-lateral leg press contractions over 8 months on: Isometric squat force- and jump, CK, myoglobin, Interleukin-6, lactate dehydrogenase, thigh circumference and PMS at 0, 24, 48 and 72 h post.	CWT and PAR = ↔ isometric squat jump. ** CWT *vs.* PAR = ↓ Change in isometric squat jump and weighted squat jump at 24, 48 and 72 hours. * CWT = ↓ PMS at 24, 48 and 72 hours. *
Vaile *et al.* (2008b) Effect of hydrotherapy on recovery from fatigue.	12 Males 32.2 ± 4.3	To determine the effect of: • **Experimental group:** Seven immersion cycles of the entire body (excluding the head and neck) for 1 min, alternating between cold water (15°C) and hot water (38°C) for a total of 14 min. • **Control group:** Seated with minimal movement for 14 min. After 10 min self-paced warm-up followed by 3 x 3-sec sprints at 70%, 80% and 90% of maximum effort, a 9 min of sustained effort consisting of 2 x 2-min and one 5 min time trial was incorporated over a 5 day period on four separate occasions separated by nine days on: Core temperature, HR, RPE, time trial- and sprint performance.	CWT *vs.* PAR = ↑ maintenance of average sprint power and time trial performance. * CWT *vs.* PAR = ↑ differences for rectal temperature. * CWT *vs.* PAR = ↑ HR on day 4 and day 5. ‡ CWT *vs.* PAR = ↔RPE CWT and PAR = ↔ RPE.
Versey *et al.* (2011) Effect of contrast water therapy duration on recovery of cycling performance: a dose-response study.	11 Males 32.1 ± 7.6	To determine the effect of: • **Experimental group 1,2,3:** 6;12 or 18 min of immersions in hot water of 38.4°C and cold water of 14.6°C, alternating every minute with a 5 sec changeover. • **Control group:** Seated for the specific duration. After a 75-min cycling protocol over a 8 day period on: Power outputs, Core body temperature, HR logged every 5 sec, RPE at the end of each sprint set, time-trial and exercise bout.	CWT of 6-min *vs.* PAR= ↑ time trial and sprint performance. CWT of 12-min *vs.* PAR= ↑ sprint total work and peak power. CWT *vs.* PAR = ↑ thermal sensation, whole body fatigue and PMS. CWT *vs.* PAR = ↔ HR and RPE.

CK = Creatine Kinase; CWT = Contrast Water Therapy; HR = Heart Rate; PAR = Passive Recovery; PMS = Perceived Muscle Soreness; RPE = Rate of Perceived Exertion.
* = p ≤0.05; ** = p >0.05; ‡ = d ≥0.5; ↑ = Increased; ↓ = Decreased; ↔ = No difference.

TABLE 3 (cont.): Descriptions of studies regarding the effects of CWT on certain physiological and performance components.

Authors, date and title of publication	Number, gender and age (years) of subjects	Intervention program	Results
Webb *et al.* (2013) The relative efficacy of three recovery modalities after professional rugby league matches.	21 Males 23.5 ± 2.6	To determine the effect of: • **Experimental group:** Three immersion cycles of the lower body up to the anterior superior iliac spine for 9 min, alternating between cold water (8-10°C) for 1 min and warm water (40-42°C) for 2 min. • **Control group:** Active recovery done on a cycle ergometer for 7 min. After 3 consecutive home games over a 6-week period on: CK, CMJ height, PMS and contact fatigue.	CWT *vs.* Active = ↑ effect on jump height at 1-18 and 18-42 hours post-match. CWT *vs.* Active = ↓ PMS at 1-18 hours post-match. CWT = ↑ beneficial effect on CK at 1-18 and 18-42 hours post-match.

CK = Creatine Kinase; CMJ = Countermovement Jump; CWT = Contrast Water Therapy; PMS = Perceived Muscle Soreness; ↑ = Increased; ↓ = Decreased.

4.2.1. Results from CWT interventions

Ten studies (French *et al.*, 2008; King & Duffield, 2009; Pournot *et al.*, 2011; Robey *et al.*, 2009; Sayers *et al.*, 2011; Stanley *et al.*, 2012; Vaile *et al.*, 2008a; Vaile *et al.*, 2008b; Versey *et al.*, 2011; Webb *et al.*, 2013) evaluated a wide range of components (physical, physiological and psychological), whereas only three (Crampton *et al.*, 2013; De Nardi *et al.*, 2011; Hamlin, 2007) reported on the physical and physiological, and four (Bahnert *et al.*, 2013; Dawson *et al.*, 2005; Elias *et al.*, 2012; Elias *et al.*, 2013) on the physical and psychological components. Coffey *et al.* (2004) and Ingram *et al.* (2009) looked at the physiological and psychological components, whereas only Gill *et al.* (2006) and Morton (2007) solely evaluated the physiological components.

A wide range of results has been reported in the literature. In this regard, studies reported no difference in CMJ (Bahnert *et al.*, 2013; Crampton *et al.*, 2013), BLa$^-$ (Coffey *et al.*, 2004; Sayers *et al.*, 2011), haemoglobin (De Nardi *et al.*, 2011), CK (Hamlin 2007; Robey *et al.*, 2009), HR (King & Duffield, 2009), sprint ability (De Nardi *et al.*, 2011) and cycling performance (Crampton *et al.*, 2013).

Three studies (Elias *et al.*, 2012; King & Duffield, 2009; Vaile *et al.*, 2008b) demonstrated a decrease in the perception of pain recorded following CWT. With regard to the physiological components, Hamlin (2007) noticed a decrease in HR after the first bout of exercises whereas Crampton and colleagues (2013) noticed an increase in HR when the players moved from the warm to the cold water. In addition, a beneficial effect was noticed in CK levels (French *et al.*, 2008; Gill *et al.*, 2006; Webb *et al.*, 2013) and in BLa$^-$ levels (Hamlin, 2007; King & Duffield, 2009). Only one study reported an increase in BLa$^-$ 1 hour after CWT exposure (Pournot *et al.*, 2011).

Pournot and associates (2011:1291) as well as Webb and associates (2013:2452) reported that CWT resulted in a less suppressed performance in MVC and CMJ than the pre-values obtained. Not only positive results were seen from CWT, negative results were reported in MVC of the quadriceps, hamstrings and hip flexor muscles in 11 males (age 27.5 ± 6 years) after a simulated team sport exercise (Ingram *et al.*, 2009). Apart from this, the latter study (Ingram *et al.*, 2009) as well as that of Hamlin (2007) reported slower times in players' sprint ability following CWT.

Concerning the intergroup results, CWT clearly demonstrated to be superior to PAR in a wide array of components. In this regard lower results were obtained after CWT than after PAR in BLa$^-$ levels (Coffey *et al.*, 2004; Morton, 2007; Sayers *et al.*, 2011), rate of perceived exertion (Coffey *et al.*, 2004), perception of muscle soreness (Elias *et al.*, 2013; Ingram *et al.*, 2009; Stanley *et al.*, 2012; Versey *et al.*, 2011; Webb *et al.*, 2013), general fatigue experienced (Stanley *et al.*, 2012; Sayers *et al.*, 2011; Versey *et al.*, 2011) and a lower increase in CK levels (De Nardi *et al.*, 2011). In addition, the latter study (De Nardi *et al.*, 2011) also reported a lower decrease in CMJ for the CWT-group than the PAR-group. An improvement was reported in CMJ (Dawson *et al.*, 2005; Elias *et al.*, 2013), as well as in sprint performance, sprint peak power (Versey *et al.*, 2011), average sprint power and time trial performance (Vaile *et al.*, 2008b). Only two studies reported a less beneficial effect following CWT than after PAR. They reported a larger decrease in either sprint ability (King & Duffield, 2009) or rowing performance (Robey *et al.*, 2009). Although these studies did not provide an explanation for this observation, this might have been as a result of internal factors of the participants.

5. SUMMARY OF THE STUDIES REGARDING CWI AND CWT

The main focus of this review was to determine the preeminent recovery modality when comparing CWI and CWT with PAR. Furthermore, the researcher also wished to investigate the effects of each modality by itself according to the effect thereof on various performance components. The results and conclusions of these studies, presented in Tables 2 and 3, will form the basis of the discussion presented in the section below.

5.1. CWI versus CWT

Only a few research studies (Bahnert *et al.*, 2013; Crampton *et al.*, 2013; De Nardi *et al.*, 2011; Elias *et al.*, 2012; Elias *et al.*, 2013; Ingram *et al.*, 2009; King & Duffield, 2009; Pournot *et al.*, 2001; Stanley *et al.*, 2012; Vaile *et al.*, 2008a; Vaile *et al.*, 2008b & Webb *et al.*, 2013) have examined the effect of both CWI and CWT as a recovery aid. All of the above-mentioned studies examined both physical and the physiological parameters excluding the studies done by Bahnert *et al.* (2013), Elias *et al.* (2012), Elias *et al.* (2013) and Ingram *et al.* (2009) who evaluated the physical and psychological components. In this regard, a number of studies reported CWI to be superior to CWT in either perceived fatigue levels, (De Nardi *et al.*, 2011; Elias *et al.*, 2012, Elias *et al.*, 2013; Stanley *et al.*, 2012), self-reported ratings of muscle soreness (Ingram *et al.*, 2009), lower jump performance decrements as well as more effective recovery in jump and RSA, (Elias *et al.*, 2012; Elias *et al.*, 2013; King & Duffield, 2009), lower decrements in isometric strength loss (Ingram *et al.*, 2009; King & Duffield, 2009), better maintenance of performance time-trial results (Pournot *et al.*, 2001; Stanley *et al.*, 2012; Vaile *et al.*, 2008b), lower levels of BLa^- (King & Duffield, 2009) or better maintenance of blood leukocytes, neutrophils and monocytes (Pournot *et al.*, 2001). In contrast to this, Webb and colleagues (2013) reported that CWT was the most effective recovery modality in their study conducted on rugby players, although CWI tended to be beneficial with regard to the recovery of the players' jump performance and their perception of muscle soreness. In addition, Crampton and co-workers (2013:3063) further reported that CWI resulted in a significantly smaller ($p < 0.05$) time to failure cycling performance and core temperature than CWT.

One study (Bahnert *et al.*, 2013) did not, however, make use of a control group, as their players were monitored weekly over a football season lasting 23 games. A quasi-experimental study design was used on 44 players and 442 jumps recorded during the season, whereas 340 thereof were classified as recovered and only 102 as unrecovered (a retest done later in the week if their result was 1 standard deviation below their previously established mean). The researchers did indeed report a statistically significant ($p \leq 0.05$) association between CWI and a greater perception of recovery. However, no associations were found with regard to physical recovery. They concluded that no associations between post-game recovery interventions and next-game performance had occurred (Bahnert *et al.*, 2013:154).

5.2. Temperature

In most studies to date, researchers have made use of water temperatures between 8 and 12°C when applying the CWI technique (Bahnert *et al.*, 2013; Bailey *et al.*, 2007; Coffey *et al.*, 2004; Corbett *et al.*,2012; Cramton *et al.*, 2013; Dawson *et al.*, 2005; Delextrat *et al.*, 2013; Douris *et al.*, 2003; Elias *et al.*, 2012; Elias *et al.*, 2013; French *et al.*, 2008; Gill *et al.*, 2006; Halson *et al.*, 2008; Hamlin, 2007; Ingram *et al.*, 2009; Jakeman *et al.*, 2009; King & Duffield, 2009; Montgomery *et al.*, 2008; Morton, 2007; Pointon & Duffield, 2012; Pournot *et al.*, 2011; Robey *et al.*, 2009; Rowsell *et al.*, 2009; Tikuisis *et al.*, 2002; Webb *et al.*, 2013) compared to hot water immersion where water temperatures range between 38–42°C (Bahnert *et al.*, 2013; Coffey *et al.*, 2004; Crampton *et al.*, 2013; Elias *et al.*, 2012; Elias *et al.*,2013; French *et al.*, 2008; Gill *et al.*, 2006; Hamlin, 2007; Ingram *et al.*, 2009; King & Duffield, 2009; Morton, 2007; Pournot *et al.*, 2011; Robey *et al.*, 2009; Sayers *et al.*, 2011; Vaile *et al.*, 2008a; Vaile *et al.*, 2008b; Versey *et al.*, 2011; Webb *et al.*, 2013). Some exceptions were, however, observed, with certain studies reporting temperatures as low as 5°C for cold water immersion (Sellwood *et al.*, 2007; Yamane *et al.*, 2006) and another a value as high as 45°C for hot water immersion (Dawson *et al.*, 2005:212). The results of the last-mentioned studies would, however, suggest that these water temperatures had no beneficial effect in minimizing the markers of DOMS or influenced power (6-sec cycling sprint and vertical jump test) (Dawson *et al.*, 2005:215; Sellwood *et al.*, 2007:396), grip strength, ventilatory threshold or artery diameter (Yamane *et al.*, 2006:577) in sedentary subjects and football players older than 18 years of age.

5.3. Duration

The recommended duration of water immersion is 20–30 min, repeated 2–3 times daily (Higgins & Kaminski, 1998:336), although the most commonly used duration indicated in the studies is 10–15 min (Ascensão *et al.*, 2011; Bahnert *et al.*, 2013; Bailey *et al.*, 2007; Coffey *et al.*, 2004; Corbett *et al.*, 2012; Dawson *et al.*, 2005; Douris *et al.*, 2003; Elias *et al.*, 2012; Elias *et al.*,2013; French *et al.*, 2008; Howatson *et al.*, 2009; Ingram *et al.*, 2009; Jakeman *et al.*, 2009; King & Duffield, 2009; Pointon & Duffield, 2012; Pournot *et al.*, 2011; Sayers *et al.*, 2011; Silva *et al.*,2011; Vaile *et al.*, 2008a; Vaile *et al.*, 2008b; Versey *et al.*, 2011).

Exceptions were seen in one study, where a total duration of 40 min for CWI was used (Halson *et al.*, 2008:337). A significantly lower heart rate ($p < 0.05$) and larger recovery sensation after CWI was reported but no significant difference in any of the blood parameters of 11 endurance-trained male cyclists (aged ± 23.8 years). According to Pournot and associates (2011:1292), a CWI duration of longer than 1–2 min may be required when the primary aim is to provoke vasoconstriction.

With regard to the warm:cold water ratio usage, 8 different studies used the same protocol where subjects were for 1 min in cold and 2 min in warm water (Bahnert *et al.*, 2012; Coffey *et al.*,2004; Dawson *et al.*, 2005; Gill *et al.*, 2006; King & Duffield, 2009; Robey *et al.*. 2009; Stanley *et al.*, 2012; Webb *et al.*, 2013) whereas 6 studies used a 1:1 min ratio alternation (Elias *et al.*, 2012; Elias *et al.*, 2013; Hamlin, 2007; Vaile *et al.*, 2008a; Vaile *et al.*, 2008b; Versey *et al.*, 2011).

A large exception was noticed in the study conducted by Sayers and colleagues (2011) as they made use of a protocol where 14 male hockey players were immersed into cold water for 30 sec and then water for 3.5 min. They, however, found no significant difference in any of the 30-sec maximal-intensity Wingate performance indices but only a moderate ($p = 0.002$) reduction in power decline after CWT. The players experienced a lower perception of fatigue and obtained a significantly ($p < 0.001$) lower BLa level after 7 min following CWT than after PAR.

5.4. Immersion depth

To date, most studies have examined the possible effects of water immersion up to either the iliac crest or spine (Ascensão *et al.*, 2011; Bahnert *et al.*, 2013; Bailey *et al.*, 2007; Coffey *et al.*, 2004; Crampton *et al.*, 2013; Corbett *et al.*, 2012; Delextrat *et al.*, 2013; De Nardi *et al.*, 2011; Gill *et al.*, 2006; Hamlin, 2007; Howatson *et al.*, 2009; Jakeman *et al.*, 2009; King & Duffield, 2009; Morton *et al.*, 2007; Pournot *et al.*, 2011; Robey *et al.*, 2009; Sellwood *et al.*, 2007; Strejcová & Konopková, 2012; Webb *et al.*, 2013). Some studies have however focused on the possible effects of whole body immersion up to the neck area, xiphoid process or meso-sternal area (Elias *et al.*, 2012; Elias *et al.*, 2013; Gordon *et al.*, 2003; Halson *et al.*, 2008; Montgomery *et al.*, 2008; Peiffer *et al.*, 2009; Peiffer *et al.*, 2010; Sayers *et al.*, 2011; Silva *et al.*, 2011; Stanley *et al.*, 2012; Stocks *et al.*, 2004; Tikuisis *et al.*, 2002; Vaile *et al.*, 2008a; Vaile *et al.*, 2008b). Only one study could be found that examined the effect of different immersion depths on the rate of sodium excretion (Epstein *et al.*, 1974:565). However, this study was excluded from the table as it was conducted in 1974. Epstein and colleagues found that an increase in water immersion depth from waist to mid-chest and then to neck level led to a significant increase in sodium and potassium excretion rate ($p < 0.05$) in nine normal male test subjects (aged 18–42 years) (Epstein *et al.*, 1974:565).

5.5. Physical Test parameters

From all of the studies examined, 14 studies (Ascensão *et al.*, 2011; Bahnert *et al.*, 2013; Bailey *et al.*, 2007; Dawson *et al.*, 2005; Delextrat *et al.*, 2013; De Nardi *et al.*, 2011; Elias *et al.*, 2012; Elias *et al.*, 2013; French *et al.*, 2008; King & Duffield, 2009; Montgomery *et al.*, 2008; Pournot *et al.*, 2011;

Rowsell *et al.,* 2009; Webb *et al.,* 2013) evaluated the effect of hydrotherapy on the subjects' explosive power, (CMJ or maximal jump height), with five studies reporting a decrease following recovery ($p < 0.05$) (Ascensão *et al.,* 2011; De Nardi *et al.,* 2011; King & Duffield, 2009; Montgomery *et al.,* 2008; Pournot *et al.,* 2011). Three of these studies indicated no effect (Bahnert *et al.,* 2013; Bailey *et al.,* 2007; Rowsell *et al.,* 2009) while four studies showed either a faster restoration or an improvement in performance after recovery (Delextrat *et al.,* 2013; Elias *et al.,* 2012; Elias *et al.,* 2013; Webb *et al.,* 2013). In addition, Vaile and co-workers (2008a:450) reported a significantly smaller ($p < 0.05$) change in isometric squat- and peak power performance during the squat jump at 24, 48 and 72 hours post-exercising following both hydrotherapies than was the case after PAR.

The largest number of researchers evaluated the participants’ sprint ability, with five studies (Ascensão *et al.,* 2011; Delextrat *et al.,* 2013; Hamlin; 2007:401; King & Duffield, 2009:1798; Rowsell *et al.,* 2009:569) showing no effect ($p > 0.05$) after either CWI or CWT and only 4 studies (De Nardi *et al.,* 2011; Elias *et al.,* 2013; King & Duffield, 2009; Pointon & Duffield, 2012:210) indicating slower sprint performances ($p < 0.05$). In contrast to these results, Elias *et al.* (2012:361), Ingram *et al.* (2009:419) and Versey *et al.* (2011:41) found that either one or both techniques were effective for restoring the subjects' sprinting ability and muscle strength of the knee extensors and flexors to the pre-exhaustive values. In addition to this, King and Duffield, (2009:1800) and Brophy-Williams and associates (2011:668) reported a reduction ($d = 0.80$) in the decline of sprint- and vertical jump ability and next-day Yo-Yo running test results at 24 h post-recovery as opposed to having applied PAR. The subjects completed either a 15-min immersion up to the mid-sternum, or 2 x 5-min immersions up to the iliac crest.

Another physical performance indicator used by researchers is MVC of either the flexor or extensor muscles of the lower or upper-body. In this regard, the studies of Ascensão *et al.* (2011), Bailey *et al.* (2007), Corbett *et al.* (2012), French *et al.* (2008), Howatson *et al.* (2009), Jakeman *et al.* (2009), Peiffer *et al.* (2009), Pournot *et al.* (2011), Sellwood *et al.* (2007), Strejcová and Konopková (2012) and Yamane *et al.* (2006), all examined the effect of hydrotherapy on the subjects' physical strength, with the most widely used test being the maximal isometric quadriceps test. Corbett *et al.*(2012), Jakeman *et al.* (2009:458), Peiffer *et al.* (2009:93) and Sellwood *et al.* (2007:396) reported that CWI had no effect on isometric power of the quadriceps muscle with Pointon and Duffield (2012:211) and Pournot *et al.* (2011:1291) both reporting a significantly increased MVC ($p = 0.03$) and Howatson *et al.* (2009:618) a 22–25% decrease in maximum isometric voluntary contraction of the quadriceps immediately after recovery.

Only three studies (Douris *et al.,* 2003; Heyman *et al.,* 2009; Yamane *et al.,* 2006) could be found that examined the maximal muscle strength of the forearm flexor muscle after hydrotherapy by using a handgrip dynometer. The study by Douris and co-workers (2003:511) reported a significant reduction in isometric grip strength after CWI was used for periods of 5 and 10 min ($p = 0.0001–0.0007$) at 10°C, with no recovery of this strength loss within 15 min following immersion. Complimentary to this, Heyman and associates (2009:1306) found no significant difference between the recovery modalities when comparing grip strength. They further reported that the values for grip strength immediately following CWI was significantly lower compared to all the other recovery time points (Heyman *et al*., 2009:1306). According to Bailey *et al.* (2007:1168), the application of cold water long enough to lower tissue temperature (around 10–15°C) can lead to declined nerve conduction velocity; muscle spindle activity; the stretch-reflex response and spasticity. This was affirmed by Ferretti *et al.* (1992:114) who reported a positive correlation between neuromuscular coordination and nerve conduction velocity to muscle temperature. Thus decrements in muscle activity can be the result of the application of CWI. In contrast to these results, other investigators found an improvement in post-exercise maximal-voluntary contraction due to the interaction between better central activation and recovery of the contractile function (Ascensão *et al.*, 2011:221; Brophy-Williams *et al.*, 2011:668). These benefits can be partly related to the hydrostatic pressure of the decreased tissue oedema (Pointon & Duffield, 2012:214).

5.6. Physiological parameters

When evaluating the literature with regard to the influence of CWI and CWT on the physiological performance variables, care should be taken interpret the results from the various studies, as comparison of post-CWI and -CWT immersion values can greatly influence the outcome of reports. If the values are compared with the baseline values obtained (e.g. prior to fatigue), no significant differences within these results will be beneficial as this is the anticipated values (state of return to full recovery).

Within this review, most studies focused on the level of Creatine Kinase (CK) and lactate (BLa^-) in the blood, as an increased CK level is regarded as a marker of structurally damaged muscle cells (Gill *et al.*, 2006:260; Kaczmarek *et al.*, 2013:38) and BLa^- as an indicator of metabolic acidosis (King & Duffield, 2009:1795). The majority (14) of the studies (Ascensão *et al.*, 2011; Bailey *et al.*, 2007; Corbett *et al.*, 2012; French *et al.*, 2008; Gill *et al.*, 2006; Howatson *et al.*, 2009; Ingram *et al.*, 2009; Jakeman *et al.*, 2009; Pournot *et al.*, 2011; Robey *et al.*, 2009; Rowsell *et al.*, 2009; Sellwood *et al.*, 2007; Vaile *et al.*, 2008a & Webb *et al.*, 2013) examined the effect of hydrotherapy on CK while 12 studies (Brophy-Williams *et al.*, 2011; Coffey *et al.*, 2004; Halson *et al.*, 2008; Hamlin, 2007; King & Duffield, 2009; Morton *et al.*, 2007; Pointon & Duffield; 2012; Pournot *et al.*, 2011; Rowsell *et al.*, 2009; Sayers *et al.*, 2011; Tikuisis *et al.*, 2002; Vaile *et al.*, 2008a) reported on the effect of CWI and CWT recovery modalities on BLa^- levels.

Corbett *et al.* (2012); Jakeman *et al.* (2009:458); Pournot *et al.* (2011:1292), Rowsell *et al.* (2009:569) and Sellwood *et al.* (2007:396) reported no significant difference ($p > 0.05$) after CWI on CK levels 24 h post-training. In contrast to this, Webb and colleagues (2013:2452) reported that CWI had a beneficial effect on CK at 18-42 h post-CWI. With regard to BLa^-, Coffey *et al.* (2004:7), Hamlin, (2007:401), Morton *et al.* (2007:469) and Sayers *et al.* (2011:298) all reported a decrease in BLa^- after CWT with six studies (Crampton *et al.*, 2013; Halson *et al.*, 2008:337; Pournot *et al.*, 2011:1291; Rowsell *et al.*, 2009:569; Silva *et al.*, 2011:49; Vaile *et al.*, 2008a:450) reporting no effect ($p \geq 0.01–0.05$) and one (King & Duffield, 2009:1798) showing a more beneficial effect after PAR. Silva *et al.* (2011:49) reported a significantly higher ($p = 0.05$) resting heart rate after the 12th and 9th min of CWI and CWT modalities respectively, than the control group, although the heart rate was not different between the studies until the 6th minute. This would reflect a higher cardiovascular stress due to the temperature of the water the subjects were immersed in which is not beneficial for recovery (Silva *et al.*, 2004:51).

Interestingly, a number of studies examined the physiological effect of hydrotherapy, by making use of CWI and CWT, on markers such as: Plasma Volume (by measuring the haematocrit and haemoglobin levels) (Bailey *et al.*, 2007; Gordon *et al.*, 2003; Ingram *et al.*, 2009; Stocks *et al.*, 2004; Tikuisis *et al.*, 2002), Na^+, K^+, HCO_3, pH, PO_2 and PO_2 (Halson *et al.*, 2008; King & Duffield, 2009; Pointon & Duffield, 2012; Stocks *et al.*, 2004) as well as heart rate (Bailey *et al.*, 2007; Coffey *et al.*, 2004; Halson *et al.*, 2008; Hamlin, 2007; Sayers *et al.*, 2011; Silva *et al.*,2011; Stanley *et al.*, 2012; Versey *et al.*, 2011).

In this regard, Halson and colleagues (2008:337) as well as Stocks and colleagues (2004:7) reported a significantly lower PO_2 level ($p < 0.05$) but no significant differences ($p > 0.05$) in PCO_2, pH, HCO_3, Na^+ and K^+ after CWI. In contrast to this, King and Duffield (2009:1799), Pointon and Duffield (2012:211) and Tikuisis *et al.* (2002:53) reported a significant reduction ($p = 0.01–0.04$) in either Na^+ and/or K^+ as well as an increased BLa^- concentration after CWI.

6. CONCLUSION

With the professionalism of the sporting arena increasing each day, researchers are prompted to find new and improved ways of optimizing performance through decreasing the time needed to recover. This has led to the development of various recovery strategies on which several studies have reported the effect there-of. Overall, the literature supports the use of either CWI or CWT as recovery techniques by the sporting fraternity. An extensive range of literature studies exist for the use of different recovery techniques, with the benefit thereof dating back as far as 1974 (Epstein *et al.*, 1974).

The use of either CWI or CWT as recovery modalities are supported by literature when the aim is to restore or improve various physical abilities (lower body explosive power (countermovement jump or vertical jump); speed (repeated sprint ability, or sprint over 10–20 m); endurance (Intermittent Yo-Yo test) and muscle strength (maximal voluntary contraction of either the lower leg flexors or extensors or the forearm)), psychological characteristics (perceived muscle soreness; perception of recovery and perception of fatigue) and physiological (Blood lactate and Creatine Kinase) components. The beneficial effect thereof can even be extended to include significant beneficial changes ($p < 0.05$) in other physiological (heart rate, skin temperature, haemoglobin and haematocrit, myoglobin and C-reactive protein); physical (cycling or running time trial; performance (game, cycling, running)) and psychological (perception of recovery and rate of perceived exertion) components. Physical performance components that did not obtain significant results were: upper as well as lower body strength (MVC of the knee extensors and flexors as well as grip strength), explosive power (vertical jump and CMJ); sprinting ability (single sprint or RSA) and performance indicators such as running, cycling or rowing peak torque and time trial. With interpretation of the physiological results, care should be taken as it is important to find the point of reference with regard to post-CWI and CWT results. Any significant changes reported from baseline over the recovery period would not be favourable as the baseline values are the pre-fatigued values and the intent of the recovery intervention would be to return to a fully recovered (pre-fatigued) state.

The studies from this review support the protocol of water temperatures ranging between 8 and 12ºC for cold water and 38 and 42ºC for warm water immersion. Nevertheless, studies were identified that made use of water temperatures from as low as 5ºC and as high as 45ºC with no beneficial effect as a result of these extreme temperatures. When the immersion period is considered, CWI protocols ranged from 10-15 min, and for the use of CWT, the most frequently used immersion cycles were those of 1 min in cold water and 2 min in warm water. However, some studies also made use of a 1:1 ratio. The total immersion duration varied widely among the studies investigated. Some researchers immersed their participants for the duration of 90 minutes in cold water (Tikuisis *et al.*, 2002:51) and reported an increase in blood glucose levels, whereas other researchers only immersed their participants for 60 seconds in an alternating fashion (Halson *et al.*, 2008:335) with changes only seen in heart rate and skin temperature. With regard to the immersion depth, the majority of researchers required their participants to immerse themselves up to iliac crest or spine. CWI was seen to be the most beneficial over a longer period of time since the acute usage thereof resulted in decrements in certain physical performance components. However, CWT showed a more beneficial effect with the acute usage thereof as the physical performance components were executed in a warm body state due to the WWI.

Certain shortcomings were, however, identified during the compilation of the literature review regarding either CWI or CWT. In this regard, the studies concerning CWT showed a lack in haematological components assessed, as predominant components were blood lactate and creatine kinase. Another aspect overlooked by the researchers that was identified is the absence of a standard protocol with regard to the water temperature, immersion period, total duration and depth of immersion used among the studies. Overall, the studies made use of males as test subjects with only three studies solitarily using females and five using males and females. An apprehension that follows from the studies using males as well as females is the rendering of the results as most of the studies did not differentiate between the genders.

The sample size used in the literature might be another concern as the populations ranged from as few as four (Silva *et al.,* 2011) up to 45 participants (Bahnert *et al.,* 2013) with Yamane and colleagues (2006) not even reporting on the population used in their study. Furthermore, the absence of a familiarization and/or warm-up session prior to the measurements were noticed in some studies whereas other researchers failed to provide a detailed description of all the methodology and variables necessary for drawing valid conclusions.

Nevertheless, the identified findings highlight the importance, usefulness and effectiveness of either CWI or CWT as recovery techniques to either significantly improve or restore certain performance components among athletes from various sports codes. This will in turn significantly minimize and improve the recovery time between training and competition sessions, allowing more time to progressively increase in intensity, volume and load, and in due course result in a higher performance outcome seen week after week.

7. REFERENCES

Ascensão, A., Leite, M., Rebelo, A.N., Magalhaes, S. & Magalhaes, J. 2011. Effects of cold water immersion on the recovery of physical performance and muscle damage following a one-off soccer match. *Journal of sport sciences,* 29(3):217-225.

Bahnert, A., Norton, K. & Lock, P. 2013. Association between post-game recovery protocols, physical and perceived recovery and performance in elite Australian football league players. *Journal of science and medicine in sport,* 16(2):151-156.

Bailey, D.M., Erith, S.J., Griffin, P.J., Dowson, A., Brewer, D.S., Gant, N. & Williams, C. 2007. Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. *Journal of sport sciences*, 25(11):1163-1170.

Banfi, G., Melegati, G., Barrasi, A. & Melzi d’Eril, G. 2009. Beneficial effects of the whole-body cryotherapy on sport haemolysis. *Journal of human sport and exercise,* 4(2):189-193.

Bleakley, C.M. & Davison, G.W. 2009. What is the biochemical and physiological rationale for using cold-water immersion in sports recovery? A systematic review. *British journal of sports medicine,* 44(3):179-187.

Bosman, J.P., Kritzinger, J.P.K., Meiring, J.H., Schumann, C.J., Abrahams, P.H. & Greyling, L.M. 2011. Medical terminology for students of the health professions. 2nd ed. Pretoria, SA: Van Schaik Publishers.

Boussuges, A., Molenat, F., Grandford, A., Regnard, J., Wolf, J., Galland, F. & Robinet, C. 2007. Cardiovascular changes induced by cold water immersion during hyperbaric hyperoxic exposure. *Clinical physiology and functional imaging,* 27(5):268-274.

Breger Stanton, D.E.B., Lazaro, R. & MacDermid, J.C. 2009. A systematic review of the effectiveness of contrast baths. *Journal of hand therapy,* 22(1):57-70.

Brophy-Williams, N., Landers, G. & Wallman, K. 2011. Effect of immediate and delayed cold water immersion after a high intensity exercise session on subsequent run performance. *Journal of sport science and medicine,* 10(4):665-670.

Burke, DG, MacNeil, SA, Holt, LE, MacKinnon, NC & Rasmussen, RL. 2000. The effect of hot or cold water immersion on isometric strength training. *Journal of strength and conditioning research,* 14(1):21-25.

Cheung, K., Hume, P.A. & Maxwell, L. 2003. Delayed onset muscle soreness. *Sports medicine,* 33(2):145-164.

Cleak, M.J. & Eston, R.G. 1992. Delayed onset muscle soreness: mechanisms and management. *Journal of sport sciences,* 10(4):325-341.

Cochrane, D.J. 2004. Alternating hot and cold water immersion for athlete recovery: a review. *Physical therapy in sport,* 5(1):26-32.

Coffey, V., Leveritt, M. & Gill, N. 2004. Effect of recovery modality on 4-hour repeated treadmill running performance and changes in physiological variables. *Journal of science and medicine in sport,* 7(1):1-10.

Connolly D.A.J., Sayers S.P. & McHugh M.P. 2003. Treatment and Prevention of Delayed Onset Muscle Soreness. *Journal of strength conditioning research*, 17(1):197–208.

Corbett, J., Barwood, M.J., Lunt, H.C., Milner, A. & Tipton, M.J. 2012. Water immersion as a recovery aid from intermittent shuttle running exercise. *European journal of sport science*, 12(6):509-514.

Crampton, D., Donne, B., Warmington, S.A. & Egaña, M. 2013. Cycling time to failure is better maintained by cold than contrast or thermoneutral lower-body water immersion in normothermia. *European journal of applied physiology,* 113(12):3059-3067.

Datta, A. & Tipton, M. 2006. Respiratory responses to cold water immersion: neural pathways, interactions, and clinical consequences awake and asleep. *Journal of applied physiology,* 100(6):2057-2064.

Dawson, B., Gow, S., Modra, S., Bishop, D. & Stewart, G. 2005. Effects of immediate post-game recovery procedures on muscle soreness, power and flexibility levels over the next 48 hours. *Journal of science and medicine in sport,* 8(2):210-221.

Delextrat, A., Calleja-González, J., Hippocrate, A. & Clarke, N.D. 2013. Effects of sports massage and intermittent cold-water immersion on recovery from matches by basketball players. *Journal of sports sciences*, 31(1):11-19.

De Nardi, M., La Torre, A., Barassi, A., Ricci, C. & Banfi, G. 2011. Effect of old-water immersion and contrast-water therapy after training in young soccer players. *Journal of sport medicine and physical fitness,* 51(4):609-615.

Douris, P., McKenna, R., Madigan, K., Cesarski, B., Costiera, R. and Lu, M. 2003. Recovery of maximal isometric grip strength following cold immersion. *Journal of strength and conditioning research,* 17(3):509-513.

Elias, G.P., Varley, M.C., Wyckelsma, V.L., McKenna, M.J., Minahan, C.L. & Aughey, R.J. 2012. Effects of water immersion on posttraining recovery in Australian footballers. *International journal of sports physiology and performance,* 7(4):357-366.

Elias, G.P., Wyckelsma, V.L., Varley, M.C., McKenna, M.J. & Aughey, R.J. 2013. Effectiveness of water immersion on postmatch recovery in elite professional footballers. *International journal of sports physiology and performance,* 8(3):243-253.

Enwemeka, C.S., Allen, C., Avila, P., Bina, J., Konrade, J. and Munns, S. 2002. Soft tissue thermodynamics before, during, and after cold pack therapy. *Medicine & science in sports and exercise,* 34(1):45-50.

Epstein, M., Miller, M. & Schneider, N. 1974. Depth of immersion as a determinant of the natriuresis of water immersion. *Experimental biology and medicine,* 146(2):562-566.

Ferretti G. 1992. Cold and muscle performance. *International journal of sports medicine,* 13(1):185-187.

Ferretti, G., Ishii, M., Moia, C. & Cerretelli, P. 1992. Effects of temperature on the maximal instantaneous muscle power of humans. *European journal of applied physiology and occupational physiology,* 64(2):112-116.

French, D.N., Thompson, K.G., Garland, S.W., Barnes, C.A., Portas, M.D., Hood, P.E. & Wilkes, G. 2008. The effects of contrast bathing and compression therapy on muscular performance. *Medicine and science in sport exercise,* 40(7):1297-1306.

Gaesser, G.A. & Brooks, G.A. 1984. Metabolic bases of excess post-exercise oxygen consumption: a review. *Medicine and science in sports and exercise,* 16(1):29-43.

Gill, N.D., Beaven, C.M. & Cook, C. 2006. Effectiveness of post-match recovery strategies in rugby players. *Sports medicine,* 40(3):260-263.

Gordon, C.J., Fogarty, A.L., Greenleaf, J.E., Taylor, N.A.S. & Stocks, J.M. 2003. Direct and indirect methods for determining plasma volume during thermoneutral and cold-water immersion. *European journal of applied physiology,* 89(9):471-474.

Halson, S.L., Quod, M.J., Martin, D.T., Gardner, A.S., Ebert, T.R. & Laursen, P.B. 2008. Physiological responses to cold water immersion following cycling in the heat. *International journal of sports physiology and performance,* 3(3):331-346.

Hamlin, M.J. 2007. The effect of contrast temperature water therapy on repeated sprint performance. *Journal of science and medicine in sport,* 10(6):398-402.

Hawkins, J. & Miller, K.C. 2012. The importance of target tissue depth in cryotherapy application. *Journal of athletic enhancement,* 1(2):1-4.

Heyman, E., De Geus, B., Mertens, I. & Meeusen, R. 2009. Effects of four recovery methods on repeated maximal rock climbing performance. *Medicine and science in sports exercise,* 41(6):1303-1310.

Higgins, D. & Kaminski, T.W. 1998. Contrast therapy does not cause fluctuations in human gastrocnemius intramuscular temperature. *Journal of athletic training*, 33(4):336-340.

Hing, W.A., White, S.G., Bouaaphone, A. & Lee, P. 2008. Contrast therapy - A systematic review. *Physical therapy in sport*, 9(3):148-161.

Holcomb, W.R. 2005. Duration of cryotherapy application. *Athletic therapy today*, 10(1):60-62.

Howatson, G., Goodall, S. & Van Someren, K.A. 2009. The influence of cold water immersions on adaptation following a single bout of damaging exercise. *European journal of applied physiology*, 105(4):615-621.

Ingram, J., Dawson, B., Goodman, C., Wallman, K. & Beilby, J. 2009. Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *Journal of science and medicine in sport*, 12(3):417-421.

Jackson, R. 1990. Waters and spas in the classical world. *Medical history*. 34(S10):1-13.

Jakeman, J.R., Macrae, R. & Eston, R. 2009. A single 10-min bout of cold-water immersion therapy after strenuous plyometric exercise has no beneficial effect on recovery from the symptoms of exercise-induced muscle damage. *Ergonomics*, 52(4):456-460.

Kaczmarek, M., Mucha, D. & Jarawka, N. 2013. Cold water immersion as a post-exercise recovery strategy. *Medicina sportiva*, 17(1):35-39.

Keatinge, W.R. 1960. The effects of subcutaneous fat and of previous exposure to cold on the body temperature, peripheral blood flow and metabolic rate of men in cold water. *Journal of physiology*, 153(1):166-178.

King, M. & Duffield, R. 2009. The effects of recovery interventions on consecutive days of intermittent sprint exercise. *Journal of strength and conditioning research*, 23(6): 1795-1802.

Lee, D.T., Toner, M.M., McArdle, W.D., Vrabas, I.S. & Pandolf, K.B. 1997. Thermal an metabolic responses to cold-water immersion at knee, hip, and shoulder levels. *Journal of applied physiology*, 82(5):1523-1530.

Leeder, J., Gissane, C., van Someren, K. & Gregson, W. 2011. Cold water immersion and recovery from strenuous exercise: a meta-analysis. *British journal of sports medicine,* 46(4):233-240.

Meeusen, R. & Lievens, P. 1986. The use of cryotherapy in sports injuries. *Sports medicine,* 3(6):398-414.

Montgomery, P.G., Pyne, D.B., Hopkins, W.G., Dorman, J.C., Cook, K. & Minahan, C.L. 2008. The effect of recovery strategies on physical performance and cumulative fatigue in competitive basketball. *Journal of sports sciences*, 26(11):1135-1145.

Morton, R.H. 2007. Contrast water immersion hastens plasma lactate decrease after intense anaerobic exercise. *Journal of science and medicine in sport,* 10(6):467-470.

Myrer, J.W., Draper, D.O. & Durrant, E. 1994. Contrast therapy and intramuscular temperature in the human leg. *Journal of athletic training,* 29(4):318-322.

Nadler, S.F., Weingand, K., Kruse, R.J. 2004. The physiological basis and clinical applications of cryotherapy and thermotherapy for the pain practitioner. *Pain physician,* 7(3):395-399.

Nédélec, M., McCall, A., Carling, C., Legall, F., Berthoin, S. & Dupont, G. 2012. Recovery in soccer, part 1- Post-match fatigue and time course of recovery. *Sports medicine*, 42(12):997-1015.

Nédélec, M., McCall, A., Carling, C., Legall, F., Berthoin, S. & Dupont, G. 2013. Recovery in soccer, part 2 - Recovery strategies. *Sports medicine,* 43(1):9-22.

Otte, J.W., Merrick, M.A., Ingersoll, C.D. & Cordova, M.L. 2002. Subcutaneous adipose thickness alters cooling time during cryotherapy. *Archives of physical medicine & rehabilitation,* 83(11):1501-1505.

Peiffer J.J., Abbiss, C.R., Nosaka, K., Peake, J.M. & Laursen, P.B. 2009. Effect of cold water immersion after exercise in the heat on muscle function, body temperatures, and vessel diameter. *Journal of science and medicine in sport*, 12(1):91-96.

Peiffer J.J., Abbiss, C.R., Watson, G., Nosaka, K., & Laursen, P.B. 2010. Effect of a 5-min cold-water immersion recovery on exercise performance in the heat. *British journal of sports medicine,* 44(6):461-465.

Petrofsky, J. S., & Laymon, M. 2009. Heat transfer to deep tissue: the effect of body fat and heating modality. *Journal of medical engineering & technology*, 33(5), 337-348.

Pointon, M. & Duffield, R. 2012. Cold water immersion recovery after simulated collision sport exercise. *Medicine and science in sports and exercise,* 44(2):206-216.

Pournot, H., Bieuzen, F., Duffield, R., Lepretre, P.M., Cozzolino, C. & Hausswirth, C. 2011. Short term effects of various water immersions on recovery from exhaustive intermittent exercise. *Journal of applied physiology,* 111(7):1287-1295.

Robey, E., Dawson, B., Goodman, C. & Beilby, J. 2009. Effect of postexercise recovery procedures following strenuous stair-climb running. *Research in sports medicine,* 17(4):245-259.

Rousset, S., Alves-Guerra, M., Mozo, J., Miroux, B., Cassard-Doulcier, A., Bouillaud, F. & Ricquier, D. 2004. The biology of mitochondrial uncoupling proteins. *Diabetes,* 53(1):130-135.

Rowsell, G.J., Coutts, A.J., Reaburn, P. & Hill-Haas, S. 2009. Effects of cold-water immersion on physical performance between successive matches in high-performance junior male soccer players. *Journal of sport sciences,* 27(6):565-573.

Sayers, M.G., Calder, A.M. & Sanders, J.G. 2011. Effect of whole-body contrast-water therapy on recovery from intense exercise of short duration. *European journal of sport science,* 11(4):293-302.

Sellwood, K.L., Brukner, P., Williams, D., Nicol, A. & Hinman, R. 2007. Ice-water immersion and delayed-onset muscle soreness: a randomised controlled trial. *British journal of sports medicine,* 41(6):392-397.

Silva, R., Cleto, L., do Valle, N., Gripp, F., Rocha-Vieira, E. & Pinto, K. 2011. Effect of water immersion on post-exercise recovery from a single leg bout of aerobic exercise. *Journal of exercise physiology*, 14(6):47-53.

Smith, L.L. 1992. Causes of delayed onset muscle soreness and the impact on athletic performance: a review. *Journal of applied sport science research,* 6(3):135-141.

Śråmek, P., Śimeékovå, Janskỳ, L., Śavlikovå, J. & Vybiral, S. 2000. Human physiological responses to immersion into water of different temperatures. *European journal of applied physiology,* 81(5):436-442.

Stanley, J., Bucheit, M. & Peake, J.M. 2012. The effect of post-exercise hydrotherapy on subsequent exercise performance and heart rate variability. *European journal of applied physiology,* 112(3):951-961.

Stanley, J., Peake, J.M., Coombes, J.S. & Buchheit, M. 2014. *European journal of applied physiology,* 114(1):147-163.

Stocks, J.M., Patterson, M.J., Hyde, D.E., Jenkins, A.B., Mittleman, K.D. & Taylor, N.A.S. 2004. Effects of immersion water temperature on whole-body fluid distribution in humans. *Acta physiologica scandinavica,* 182(1):3-10.

Strejcová, B. & Konopková, R. 2012. The effect of active recovery, cold water immersion and passive recovery on subsequent knee extension and flexion strength. *Acta Universitatis Palackianae Olomucensis. Gymnica,* 42(3):39-47.

Tikuisis, P., Eyolfson, D.A., Xu, X & Giesbrecht, G.G. 2002. Shivering endurance and fatigue during cold water immersion in humans. *European journal of applied physiology,* 87(1):50-58.

Tomlin, D.L. & Wenger, H.A. 2001. The relationship between aerobic fitness and recovery from high intensity intermittent exercise. *Sports medicine,* 31(1):1-11.

Vaile, J., Halson, S., Gill, N. & Dawson, B. 2008a. Effect of hydrotherapy on the signs and symptoms of delayed onset muscle soreness. *European journal of applied physiology,* 102(4):447-455.

Vaile, J., Halson, S., Gill, N. & Dawson, B. 2008b. Effect of hydrotherapy on recovery from fatigue. *International journal of sports medicine,* 29(7):539-544.

Van Tubergen, A. & van der Linden, S. 2002. A brief history of spa therapy. *Annals of the rheumatic diseases,* 61(3):273-275.

Van Wyk, D. & Lambert, M.I. 2009. Recovery strategies implemented by sport support staff of elite rugby players in South Africa. *South African journal of physiotherapy,* 65(1):1-6.

Versey, N., Halson, S. & Dawson, B. 2011. Effect of contrast water therapy duration on recovery of cycling performance: a dose-response study. *European journal of applied physiology,* 111(1):37-46.

Webb, N.P., Harris, N.K., Cronin, J.B. & Walker, C. 2013. The relative efficacy of three recovery modalities after professional rugby league matches. *Journal of strength and conditioning research,* 27(9):2449-2455.

Weston, C.F.M., O'Hare, J.P., Evans, J.M. & Corrall, R.J.M. 1987. Haemodynamic changes in man during immersion in water at different temperatures. *Clinical sciences,* 73(6):613-616.

Wilcock, I. M., Cronin, J.B. & Hing, W.A. 2006. Physiological Response to Water Immersion: A Method for Sport Recovery? *Sports medicine,* 36(9):747-765.

Wilmore, J.H., Costill, D.L. & Kenney, W.L. 2008. Physiology of sport and exercise. 4th ed. USA: Human Kinetics.

Xu, X., Castellani, J.W., Santee, W. & Kolka, M. 2007. Thermal responses for men with different fat compositions during immersion in cold water at two depths: prediction versus observation. *European journal of applied physiology,* 100(1):79-88.

Yamane, M., Teruya, H., Nakano, M., Ogai, R., Ohnishi, N. & Kosaka, M. 2006. Post-exercise leg and forearm flexor muscle cooling in humans attenuates endurance and resistance training effects on muscle performance and on circulatory adaptation. *European journal of applied physiology,* 96(5):572-580.

CHAPTER 3

[redacted]

[redacted]

3

THE EFFECT OF COLD WATER IMMERSION OVER A 48-HOUR RECOVERY PERIOD AFTER AN INTENSE ANAEROBIC SESSION IN A COHORT OF MALE UNIVERSITY-LEVEL RUGBY PLAYERS

(WILL BE SUBMITTED TO: **THE JOURNAL OF STRENGTH AND CONDITIONING RESEARCH)**

TITLE: THE EFFECT OF COLD WATER IMMERSION OVER A 48-HOUR RECOVERY PERIOD AFTER AN INTENSE ANAEROBIC SESSION IN A COHORT OF MALE UNIVERSITY-LEVEL RUGBY PLAYERS

RUNNING HEAD: PHYSICAL AND HAEMATOLOGICAL COMPONENT CHANGES OVER 48 HOURS DUE TO COLD WATER IMMERSION

LABORATORY: INSTITUTE FOR SPORT SCIENCE AND DEVELOPMENT, FNB PUK HIGH PERFORMANCE INSTITUTE OF SPORT, NORTH-WEST UNIVERSITY, POTCHEFSTROOM CAMPUS, POTCHEFSTROOM, SOUTH-AFRICA

AUTHORS: ADÉLE BROODRYK, CINDY PIENAAR, MARTINIQUE SPARKS AND BEN COETZEE

CORRESPONDING AUTHOR:
CINDY PIENAAR
SCHOOL OF BIOKINETICS, RECREATION AND SPORT SCIENCE
INTERNAL BOX 494
FACULTY OF HEALTH SCIENCES NORTH-WEST UNIVERSITY
POTCHEFSTROOM CAMPUS
POTCHEFSTROOM
2520
SOUTH-AFRICA
PHONE: +27 18 2994206
FAX: +27 182992022
EMAIL: cindy.pienaar@nwu.ac.za

THE EFFECT OF COLD WATER IMMERSION OVER A 48-HOUR RECOVERY PERIOD AFTER AN INTENSE ANAEROBIC SESSION IN A COHORT OF MALE UNIVERSITY-LEVEL RUGBY PLAYERS

ADELE BROODRYK[1], CINDY PIENAAR[1], MARTINIQUE SPARKS[1], AND BEN COETZEE[1]

[1] Physical Activity, Sport and Recreation Research Focus Area; Faculty of Health Sciences, North-West University, South Africa

ABSTRACT

The study examined the effect of two recovery interventions, cold water immersion (CWI) and passive recovery (PAR), on 14 haematological and four physical components over a 48-hour period in 23 male university rugby players. The haematological and physical components were evaluated at baseline, 3 minutes post-training and at 0, 24 and 48 hours post-recovery. The utmost finding of the current study is the earlier convalescence to baseline levels (indicating recovery) in the CWI-group, with three (blood lactate (BLa^-), sodium (Na^+) and haemoglobin) out of the nine variables returning to baseline values at 0 hours post-recovery. Contrary to this, the PAR-group did not demonstrate recovery to baseline values in any of the variables immediately following PAR; however an improvement was seen in vertical jump test height (VJTH) at all the time points. Significant decreases ($p \leq 0.05$) were seen in VJTH, PO_2 and Na^+ from post-anaerobic to immediately following either CWI or PAR (except for VJTH). Significant increases ($p \leq 0.05$) were observed in VJTH, plasma glucose, and Na^+ from 0h post-recovery to 48 hours post-recovery for both CWI and PAR. PO_2 also significantly increased ($p \leq 0.05$) from 0h to 24 and 48h post-CWI and for the PAR-group at 48 hours. CWI tended to have a faster recovery rate than PAR over a 24-hour period. In conclusion, CWI could be useful over a time period (of 24 hours). However, it may be detrimental to the acute recovery (0h) of physical components.

KEY WORDS: cryotherapy, haematological, physical, training, recovery

INTRODUCTION

Rugby union has become such a popular team sport worldwide that the occurrence of matches have increased substantially, resulting in players often participating every seven days for several weeks (5,39). The result of the increase in match and training exposure is that injuries occur more frequently due to more fatigued musculoskeletal, nervous and metabolic systems as players have to train and compete while their muscles are still in a state of disrepair (26,39). In order to decrease the physiological stress, cope with the adaptive stress and be able to train and compete at the required intensity and load, players need to optimally recover between training and competition (39). The ultimate goal of effective recovery sessions is to repair damaged tissue, replenish depleted energy stores and remove accumulated metabolites to decrease fatigue and maximise the training response (22). Despite a wide range of recovery techniques, cold water immersion (CWI) is one of the most popular techniques used by team sports and seems to be superior to passive recovery (PAR) (14,32,39). Despite CWI being the most popular recovery technique, the physiological and haematological benefits that can be derived from acute CWI sessions above those of PAR are not always investigated or confirmed through research.

Nédélec and colleagues (32) provided a brief summary of various studies that immersed the athlete’s whole body or parts of the body in cold water at temperatures of between 9 and 15°C for the duration of 5–20 minutes. Despite the expectation that CWI will benefit the acute recovery of various physical and physiological parameters, CWI (up to the level of the iliac crest for 10 min at 10°C) after the execution of a prolonged intermittent shuttle run did not lead to significant improvements in vertical jump height in twenty healthy men (age 22.3 years) (3). CWI even caused a statistically significant ($p < 0.01$) 27% decrease in jump height before and after a series of jumps on a force platform in six male subjects (age 31 years) (16). However, Delextrat and colleagues (10) reported an improvement in countermovement jump (CMJ) height of eight males (age 23±3 years) and eight females (age 22±2 years) after five cycles of 2 min immersions up to the iliac crest. Furthermore, no significant difference was observed because of CWI (up to the level of the mesosternal in water of 11.5°C for cycles of 60 sec with 120 sec of seated rest in between) for pH, bicarbonate (HCO_3), sodium (Na^+), potassium (K^+) or the partial pressure of carbon dioxide (PCO_2) in endurance cyclists after a 40-min cycling session in the heat (20). According to Banfi and colleagues (4) the application of cryotherapy in the form of cold air on ten male athletes (age 26 years) caused a statistically significant ($p < 0.01$) decrease in blood haemoglobin levels with no significant change in haematocrit levels. A study on male rugby players also observed a significant enhancement ($p = 0.03$) in the immediate recovery of maximal voluntary knee contraction strength after a simulating collision exercise (33).

In contrast to CWI, PAR refers to recovery technique where an athlete rests passively, usually in a supine position for a certain duration of time so that the body recuperates to its pre-exercising state (30). This technique may be beneficial as players have to travel frequently and sit passively for long bouts.

Nevertheless, PAR led to a constant decrease in repeated sprint ability as well as a large decrease in CMJ height of 18 male soccer players (age 15.5±1.0 years) (12). Furthermore, the application of PAR caused an increase in creatine kinase in 41 males (age 21.5±4.6) after an exhaustive intermittent exercise over a two-day period (34). Contrary to this, Pointon and Duffield (33) reported a greater distance coverage following PAR on male rugby players whereas Halson and colleagues (20) reported no significant effect ($p > 0.05$) in blood glucose, K^+, Na^+ and BLa^- levels following PAR.

According to Elias and associates (14) as well as Delextrat and associates (10), CWI tends to be superior to PAR in aiding CMJ height results. In this regard, studies reported lower decreases in CMJ and repeated sprint ability, as well as a lower increase in creatine kinase for CWI than was the case with PAR in soccer and football players (12,14). In contrast, compared to PAR, CWI led to slower sprint times although the total sprint times were faster in the CWI-group in 11 males (age 27.5±6 years) after a simulated team sport exercise (24). These results were confirmed by Pournot and colleagues (34) who also observed statistically significantly ($p < 0.05$) slower sprint times for CWI *vs.* PAR in 41 males (age 21.5±4.6) after an exhaustive intermittent exercise over a two-day period. Additionally, another study revealed BLa^- to be statistically significantly lower ($p < 0.04$) following PAR than CWI after a simulating collision team sport (33).

It is in the light of the abovementioned shortcomings and contrasting findings that the objective of this study was to determine the effects of CWI compared to PAR over a 48-hour period on the physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players.

METHODS

Experimental Approach to the Problem

The specific hypothesis under scrutiny was that compared to PAR, CWI of 20-min after an anaerobic session of shuttle runs will lead to a significant negative effect in a cohort of male university-level rugby players' physical components but a significant positive effect on players' haematological components. Therefore a cross-sectional, pre-post-test with convenient sampling was used to test the specified hypothesis. The control (PAR) and experimental (CWI) groups were subjected to a series of physical performance tests, and haematological analyses were performed at baseline (before the ingestion of breakfast), pre-anaerobic (before the anaerobic) session, post-anaerobic (3 minutes directly after the anaerobic training session), post-recovery (3 minutes directly after the recovery session), 24 h post-recovery (24 hours directly after the recovery session) and 48 h-post-recovery (48 hours directly after the recovery session).

Subjects

Twenty three u/21 male rugby-players from a Rugby Institute in a South Africa voluntarily participated in the study and ethical approval was granted by the North-West University's Ethics Committee (number: NWU-00201-14-A1). The study was conducted according to the ethical guidelines and principles of the international Declaration of Helsinki and the ethical guidelines of the National Health Research Ethics Council. The group consisted of 13 backline players (numbered nine to fifteen) and 10 forwards (numbered one to eight). The players were randomly assigned to either a control (*n* = 11) or experimental (*n* = 12) group. Body stature and mass of players are presented in Table 1. Only rugby players actively involved and training as members of the specific Rugby Institute as well as those without injuries was eligible to participate in the study. The competitive rugby-playing experience of these players varied between 4 and 15 years with an average of 10.20±2.80 years. Each subject was instructed to sleep at least 8 hours during the evening and morning prior to the testing session. They also had to abstain from ingesting any drugs or participating in strenuous physical activity that may influence the physical or physiological responses of the body for at least 48 hours before the scheduled test. Subjects had to maintain the same diet during the week of testing. The subjects arrived at the testing sessions in a rested and fully hydrated state. This was monitored be means of an urine sample.

TABLE 1. Subject characteristics *

	Control group (*n* = 11)	Experimental group (*n* = 12)
Body stature (cm)	179.7 ± 6.7	183.2 ± 5.8
Body mass pre-recovery (kg)	88.5 ± 12.1	94.7 ± 13.1
Body mass post-recovery (kg)	89.0 ± 12.2	95.2 ± 13.9

* Values are mean ± *SD*

The players were tested during the in-season phase of their periodization cycle. Prior to testing, they had already completed three months of a combined rugby conditioning program which consisted of field training sessions five times a week and gym resistance training sessions four times a week. The field training sessions were focused on rugby-specific drills, skills and activities aimed at improving the players' fitness levels. The gym resistance training sessions focused on improving players' functional muscle strength as well as explosive power.

Testing Procedures

A week before commencement of the research project the players were informed about the nature of the study, and all potential risks and benefits were explained to them. Informed consent for the investigation was also requested from the players during this session. The research project was conducted for three consecutive days over two consecutive weeks. During the first day of testing the players reported to the laboratory at 6:00 am in the morning for baseline values to be measured. The baseline testing took place in a fasting state just after players had woken up. Players were afforded the opportunity to complete the demographic and general information questionnaire. Thereafter, body mass and stature were measured, followed by a blood sample collection by means of a finger prick to evaluate the lactate level and different blood variables using the i-STAT portable analyser (Abbot Point of Care Inc., Princeton, New Jersey, USA). The players then performed the explosive power and hand grip strength tests without any prior warm-up period completed. Players were then allowed to eat breakfast, after which they again reported to the laboratory in groups of four players each so that all the above-mentioned measurements could be repeated. Players were then subjected to a high-intensity anaerobic training session for 15 minutes. Exactly three minutes after the anaerobic session all measurements were repeated to evaluate the effect of the training session on the body. This was followed by a 20-min CWI recovery session for the experimental group and 20 min of PAR for the control group. Exactly three minutes, and 24 and 48 hours after completion of the different recovery techniques all the measurements were completed again to assess the acute and longer-term effects of the two recovery techniques on the different measurements.

Physical performance tests

Explosive power test. Lower body explosive power was measured by means of the Vertical Jump Test (VJT) by using a Vertex (Swift Performance Equipment, Lismore, Australia) according to the method of Harman et al. (23). The VJT is regarded as an objective (r = 0.90) and valid test (r = 0.93) to determine the peak anaerobic power output of subjects (35). The tester adjusted the height of the stack of moveable colour-coded horizontal plastic vanes to be within the player's standing reach height. The highest vane that could be reached and pushed forward with the dominant hand while the player stood flat footed determined the standing height. The vanes stack was then raised to a measured distance (marked on the shaft holding the vanes) so that the player could not jump higher or lower than the set of vanes. Without a preparatory or stutter step, the player then performed a counter movement by quickly flexing the knees and hips, moving the trunk forward and downward, and swinging the arms backwards. During the jump, the dominant arm reached upward while the non-dominant arm moved downward relative to the body. At the highest point in the jump, the player tapped the highest possible vane with the finger of the dominant hand. The score was the vertical distance between the heights of the highest vane tapped during the standing vertical reach and the vane tapped at the highest point of the jump. The better of two trials was recorded to the nearest 0.5 cm (the distance between adjacent vanes). The subject performed a minimum of two trials with a 30-second rest period between each trial.

Power output during the VJT was measured for each jump with a Tendo^{TM} Power Output Unit (Tendo Sports Medicine, Trensin, Slovak Republic). The Tendo^{TM} unit consisted of a transducer attached to the waist of each player measuring the linear displacement and time. Subsequently, jump velocity was calculated and power determined. Peak power output was recorded for each jump and used for subsequent analyses. According to Hoffman et al. (24), the test-retest reliability of the Tendo^{TM} unit is $r \geq 0.92$.

Grip strength test. Grip strength was measured with a hand grip dynamometer (Smedley's Dynamometer^{TM}, Tokyo). The rationale for including this test was to evaluate the central nervous system's ability to forcefully contract the forearm muscles to generate maximal force. This measurement has an interclass reliability of 0.99 for the preferred hand in basketball players (18), and validity of 0.71 for the dominant hand (6). The grip dynamometer was set at zero before the start of the test. The test was conducted as set out in the Eurofit test manual (15) with the size of the player's hand fitted to the dynamometer by adjusting the base and the handle of the dynamometer with the handle resting on the middle of the phalange, and the base on the first metacarpal. Players then took a standing position with the arm raised vertically above the head, palms facing inward. The test was performed by gripping the dynamometer as hard as possible whilst moving the arm through a 180° arc for 3 seconds. The arm remained straight (fully extended at the elbow) throughout the movement. Two trials were allowed for the dominant hand and the best score was recorded. Recording of each trial took place to the nearest kilogram and if the difference in scores was more than 3 kg, the test was repeated and the best of the three measurements was used.

Haematological components

Blood analysis. Capillary blood samples were drawn from the hyperaemic fingertip by means of a finger prick and collected into duplicate 100µL heparinised capillary tubes (Bacto laboratories, Pty. Ltd. New South Wales, Australia). Prior to sampling, the punctured site was cleaned with an alcohol wipe, dried, and the first drop post-puncture excluded from the sample. The sample was then immediately expelled from the capillary tubes into the sample wells of one CG_8^+ cartridge and any air bubbles were removed from the sample prior to the cartridge being closed (9). These cartridges were removed from the stored area (2–8°C) 5 min prior to the testing session, as per manufacturer's instructions. Once the removal of the bubbles was completed, the cartridge was transferred into the i-STAT clinical portable, which determines the concentration of up to 19 haematological variables from small samples (60-100µL) of capillary blood within 90–120 seconds. The following haematological components were measured: BLa^-, PO_2, partial carbon dioxide (PCO_2), total carbon dioxide (TCO_2), saturated oxygen (SO_2), HCO_3, base excess (BEx), pH, Na^+, K^+, plasma glucose, haemoglobin and haematocrit. Insufficient blood sample or mistakes in the hardware was detected by the self-calibrating battery-powered analyser which contained its own error detection system. The i-STAT analyser was calibrated to a controlled solution according to the manufacturer's specifications by means of an electronic stimulation prior to each testing session. An intra-class reliability for blood PO_2 (r = 0.60–0.88), PCO_2 (r = 0.60–0.95) SaO_2 (r = 0.28–0.77), HCO_3 (r = 0.66–0.86), BLa^- (r = 0.97) and pH (r = 0.62–0.88) across various exercise intensities during either a VO_2 max cycle test or an intermittent treadmill running test in 7 and 11 males was reported by Dascombe et al. (9).

Recovery techniques

CWI:

The protocol for CWI required subjects to sit in an upright position with legs outstretched in a pool of cold water just above the umbilicus, with their hands and arms folded over their chests and away from the water at all times. Subjects were exposed to water maintained at a temperature of 8±1°C for a period of 20 minutes. This time period is in accordance with other studies (3,34).

PAR:

This protocol required subjects to sit in a comfortable upright position in a laboratory of which the temperature was maintained at 19°C for 20 minutes.

Statistical Analysis.

The Statistical Data Processing package SPSS (25), was used to process the data. Firstly, a Ward's cluster analysis was performed to determine what variables could be clustered together so that only one variable from a cluster of variables could be used for further data analysis. Next, the descriptive statistics (minimum, maximum and average) of all variables were calculated. Thirdly, a linear mixed model analysis was performed to investigate time and variable differences with an autoregressive 1 heterogeneous (AR1-Heterogeneous) structure. Players were inserted as subjects and the time points were entered as fixed effects into the model. Possible player interdependency was therefore taken into account. Lastly, between-group differences in subject characteristics and variables over all the time points were examined using a one-way analysis of variance (ANOVA). The level of significance was set at $p \leq 0.05$. Effect sizes were calculated to determine practically significant differences within and between the experimental and control groups for all variables measured at different time points. Effect size (ES) (expressed as Cohen's D-value) was interpreted as follows: an ES of more or less 0.8 as large, an ES of more or less 0.5 as moderate and an ES of more or less 0.2 as small (8).

Due to the fact that the results obtained from the mixed models showed no significant differences between measurements at the fasting (baseline) and non-fasting (pre-anaerobic) time points, only measurement results of the pre-anaerobic time point were used in the rest of the analyses and were therefore referred to as the baseline values. However, it must be noted that in cases where PAR or CWI had the desired recovery effect on the different measurements of players, the post-recovery values would be similar to those of the pre-anaerobic values. This would mean that players' physiological and physical state returned to levels observed before the execution of the anaerobic, exhausting session. On the other hand it is also possible that the different recovery techniques had a positive effect on some measurements by decreasing these values (such as BLa^-) from the pre-anaerobic to the post-recovery time points. *Vice versa*, recovery techniques may also lead to an increase in some measurements (such as power output during the VJT) from the one time point to the next. Therefore all of these trends in results would be an indication that the recovery techniques led to physiological and physical recovery, despite the absence of statistical or practically significant changes.

RESULTS

Cold water immersion (CWI)

After the cluster analysis was done, the following haematological variables were selected to represent the remaining variables (thus only their significance was calculated and revealed): BLa^-; PO_2; Na^+; plasma glucose and haemoglobin. Descriptive statistics as well as significance of haematological and physical measurement differences between five time points for the CWI-group are presented in Table 2.

Haematological components: The results from Table 2 indicate a statistically ($p \leq 0.05$) and practically significant higher ($d \geq 0.8$) post-anaerobic BLa^- than all other time points, indicating metabolic acidosis and the fatiguing effect that the anaerobic training session had. In addition, BLa^- only recovered to baseline at 24 hours post-recovery. PO_2 was the only other haematological parameter which showed a practically significantly ($d \geq 0.8$) lower value at 24 hours post-recovery than values at all other time points. A statistically significantly ($p \leq 0.05$) higher PO_2 was also observed for 48 hours post-recovery than the 0 hours post-recovery time point, demonstrating an increase of 19%. Practically significant ($d \geq 0.8$) differences in Na^+ values between the following three time points were also found: pre-anaerobic and post-anaerobic; post-anaerobic and post-recovery as well as post-recovery and 48 hour post-recovery. However, blood glucose showed a dissimilar trend with practically significant ($d \geq 0.8$) differences observed between 48 hours post-recovery and both 0-hour (18% increase) and 24-hour (10% increase) post-recovery. Players' haemoglobin values stayed more or less constant.

TABLE 2. Descriptive statistics as well as significance of haematological and physical measurement differences between five time points for the CWI-group

	Time point				
Cluster-reduced Haematological components	Pre-An	Post-An	0h Post-CWI	24h Post-CWI	48h Post-CWI
BLa^-	1.3 ± 0.5 $^{a\,*}$	5.2 ± 2.7 $^{abcd\,*\#\blacksquare\phi}$	1.4 ± 0.4 $^{b\,\#}$	0.9 ± 0.2 $^{c\,\blacksquare}$	1.1 ± 0.4 $^{d\,\phi}$
PO_2	62.2 ± 4.2 *	64.4 ± 13.1 $^{\#}$	55.3 ± 8.8 $^{a\,*\#\blacksquare\phi}$	63.8 ± 8.7 $^{\blacksquare}$	68.3 ± 8.3 $^{a\phi}$
Na^+	142.3 ± 1.5 *	143.6 ± 2.0 $^{*\#}$	142.0 ± 1.3 $^{\#\blacktriangleright}$	142.7 ± 0.5	143.2 ± 1.4 $^{\blacktriangleright}$
Plasma glucose	97.3 ± 7.7	103.6 ± 16.6	90.7 ± 9.1 *	98.7 ± 17.9 $^{\#}$	110.2 ± 28.7 $^{*\#}$
Haemoglobin	16.3 ± 0.8	16.3 ± 0.8	16.2 ± 0.7	16.6 ± 1.0	16.2 ± 1.1
Remaining Haematological components					
pH	7.46 ± 0.0	7.37 ± 0.1	7.45 ± 0.0	7.45 ± 0.0	7.47 ± 0.0
PCO_2	34.4 ± 2.1	29.1 ± 3.0	34.2 ± 2.5	34.7 ± 2.7	32.7 ± 2.5
TCO_2	25.1 ± 1.6	18.2 ± 4.2	24.8 ± 1.1	24.9 ± 1.2	24.8 ± 1.4
SO_2	92.5 ± 1.6	90.6 ± 5.9	88.7 ± 4.4	92.4 ± 3.8	94.3 ± 2.8
HCO_3	24.2 ± 1.8	17.2 ± 4.2	23.6 ± 1.0	23.8 ± 1.1	23.7 ± 1.4
BEx	0.2 ± 1.4	-8.0 ± 5.2	-3.6 ± 1.0	-2.7 ± 1.3	0.8 ± 1.6
K^+	5.2 ± 0.3	5.0 ± 0.5	5.3 ± 0.4	5.7 ± 0.6	5.4 ± 0.6
Ca^+	1.3 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.0	1.2 0.1
Haematocrit	47.9 ± 2.3	48.0 ± 2.4	47.6 ± 2.1	48.7 ± 3.0	47.6 ± 3.4
Physical components					
VJT-H (cm)	49.1 ± 8.5	51.5 ± 10.5 *	45.3 ± 5.3 $^{*\#}$	50.6 ± 5.6	53.9 ± 5.9 $^{\#}$
VJT-PP (W)	2454.6 ± 385.8	2579.8 ± 366.8	2351.2 ± 466.8	2624.3 ± 414.5	2513.5 ± 228.6
VJT-PS ($m.s^{-1}$)	2.7 ± 0.4	2.8 ± 0.3 *	2.5 ± 0.3 $^{*\#}$	2.8 ± 0.2 $^{\#}$	2.8 ± 0.5
Grip strength (kg)	57.5 ± 7.0	56.1 ± 3.0	56.9 ± 5.4	54.3 ± 4.9	56.6 ± 6.0

Data are mean ± *SD*

BEx = Base Excess; BLa- = blood lactate; Ca+ = Calcium; CWI = Cold Water Immersion; HCO_3 = Bicarbonate; K+ = Potassium; Na_+ = Sodium; Pre-An = Pre-Anaerobic; Post-An = Post-Anaerobic; 0h Post-CWI = Immediately following CWI; 24h Post-CWI = 24 hours following CWI; 48h Post-CWI = 48 Hours following CWI; PCO_2 = Partial Carbon dioxide; PO_2 = Partial Oxygen; PP = Peak Power; PS = Peak Speed SO_2 = Saturated Oxygen; TCO_2 = Total Carbon dioxide; VJT = Vertical Jump Test; VJT-H = Vertical Jump Test Height

abcd - Significant differences ($p \leq 0.05$) for corresponding letters between different time points

*** # ■ ɸ** Δ **►** - Large practical significant effect ($d \geq 0.8$) for corresponding symbols between different time points

Physical components: Although no statistically significant ($p \leq 0.05$) differences were observed for any of the physical components between the different time points, a large practically significant difference ($d \geq 0.8$) in VJT-H was observed between post-recovery and both post-anaerobic and 48-hour post-recovery. VJT-PS showed more or less a similar trend with the post-recovery value that showed a practically significant difference when compared with values at the post-anaerobic and 48-hour post-recovery time points. The majority of physical components returned to levels above pre-anaerobic levels at the 24-hour post-recovery time point whereas all the values were lower at the post-recovery compared to pre-anaerobic time point. However, grip strength did not return to pre-anaerobic levels at any of the post-recovery time points.

Passive recovery (PAR)

Descriptive statistics as well as significance of haematological and physical measurement differences between five time points for the PAR-group are presented in Table 3.

Haematological components: All the haematological variables showed practical significant higher values ($d \geq 0.8$) post-anaerobic when compared to the post-recovery time point. However, only BLa^- and Na^+ were the components that obtained practically significant differences between pre- and post-anaerobic time points. PO_2, Na^+ and plasma glucose achieved practically significant ($d \geq 0.8$) differences between the post-recovery and 48-hour post recovery time points. PO_2 was the only haematological variable that displayed a practically significant ($d \geq 0.8$) lower value (9% difference) at the 0-hour time point compared to the pre-anaerobic time point. Similarly, plasma glucose was the haematological variable that achieved a practically significant ($d \geq 0.8$) lower value for the 0 hour post-recovery than both 24 (13% difference) and 48 hours (16% difference) post-recovery values.

Physical components: Again no statistical significant differences were observed for any of the physical parameters. However, a practically significant increase were observed for VJT-PP (8.9%) and VJT-PS (9.7%) immediately following PAR to 24 hours post-PAR. The results obtained for VJT-H indicated an improvement from baseline over all the time points, whereas VJT-PS and -PP only recovered at 24 hours post-PAR. In addition, grip strength resulted in a non-significant decrease from baseline across all the recovery time points, with a 7.2% decrease observed at 24 hours post-PAR and only recovering to a baseline value at 48 hours post-PAR.

TABLE 3. Descriptive statistics as well as significance of haematological and physical measurement differences between five time points for the PAR-group

	Time point				
Cluster-reduced Haematological components	Pre-An	Post-An	0h Post-PAR	24h Post-PAR	48h Post-PAR
BLa^-	1.3 ± 1.0 *	4.5 ± 3.3 $^{*\#\blacksquare\phi}$	2.4 ± 1.5 $^{\#}$	1.0 ± 0.3 $^{\blacksquare}$	1.2 ± 0.4 $^{\phi}$
PO_2	64.7 ± 6.5 *	68.6 ± 9.8 $^{a\#}$	58.9 ± 6.2 $^{a*\#\blacksquare}$	63.9 ± 5.2	65.0 ± 5.0 $^{\blacksquare}$
Na^+	141.8 ± 1.1 $^{*\#}$	143.2 ± 1.4 $^{*\blacksquare\phi}$	142.2 ± 1.3 $^{\blacksquare\Delta}$	142.2 ± 1.3 $^{\phi\blacktriangleright}$	143.4 ± 1.3 $^{\#\Delta\blacktriangleright}$
Plasma glucose	100.8 ± 17.7	108.5 ± 15.8 *	91.2 ± 11.3 $^{*\#\blacktriangleright}$	104.8 ± 19.9 $^{\#}$	107.9 ± 13.6 $^{\blacktriangleright}$
Haemoglobin	16.5 ± 0.6	16.9 ± 1.0 $^{*\#}$	16.1 ± 0.9 *	16.5 ± 0.8	16.5 ± 0.8 $^{\#}$
Remaining Haematological components					
pH	7.46 ± 0.0	7.34 ± 0.1	7.46 ± 0.0	7.45 ± 0.0	7.48 ± 0.0
PCO_2	33.9 ± 1.4	29.0 ± 1.8	33.3 ± 2.1	34.8 ± 2.0	32.9 ± 2.2
TCO_2	25.3 ± 2.2	16.7 ± 2.4	24.6 ± 1.1	25.0 ± 1.3	25.6 ± 1.4
SO_2	93.3 ± 2.0	92.0 ± 2.5	91.5 ± 2.7	93.0 ± 1.9	94.1 ± 1.6
HCO_3	24.3 ± 1.8	15.8 ± 2.3	23.7 ± 1.1	24.0 ± 1.3	24.6 ± 1.3
BEx	0.6 ± 2.2	-10.0 ± 3.1	0.9 ± 1.6	0.0 ± 1.6	1.18 ± 1.4
K^+	5.7 ± 0.4	5.2 ± 1.0	5.4 ± 1.2	5.6 ± 0.5	5.3 ± 0.5
Ca^+	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.0	1.2 ± 0.1	1.2 ± 0.1
Haematocrit	48.6 ± 1.7	49.7 ± 2.6	47.4 ± 2.7	48.3 ± 2.1	47.6 ± 2.4
Physical components					
VJT-H (cm)	49.1 ± 11.2	54.7 ± 9.4	52.5 ± 8.6	50.8 ± 6.9	54.5 ± 8.1
VJT-PP (W)	2571.2 ± 338.6	2588.3 ± 258.7	2426.0 ± 308.1 *	2663.2 ± 298.5 *	2569.4 ± 335.2
VJT-PS ($m.s^{-1}$)	3.0 ± 0.4	3.0 ± 0.4	2.8 ± 0.3 *	3.1 ± 0.3 *	3.0 ± 0.4
Grip strength (kg)	52.5 ± 5.4	51.2 ± 5.3	50.4 ±7.0	48.7 ± 5.3	52.3 ± 5.6

Data are mean ± *SD*

BEx = Base Excess; BLa- = blood lactate; Ca+ = Calcium; HCO_3 = Bicarbonate; K+ = Potassium; Na_+ = Sodium; PAR = Passive Recovery; Pre-An = Pre-Anaerobic; Post-An = Post-Anaerobic; 0h Post-PAR = Immediately following PAR; 24h Post-PAR = 24 hours following PAR; 48h Post-PAR = 48 Hours following PAR; PCO_2 = Partial Carbon dioxide; PO_2 = Partial Oxygen; PP = Peak Power; PS = Peak Speed SO_2 = Saturated Oxygen; TCO_2 = Total Carbon dioxide; VJT = Vertical Jump Test; VJT-H = Vertical Jump Test Height

abcd - Significant differences ($p \leq 0.05$) for corresponding letters between different time points

*** # ■ ϕ** Δ **►** - Large practical significant effect ($d \geq 0.8$) for corresponding symbols between different

Intergroup results obtained are presented in Figure 1.

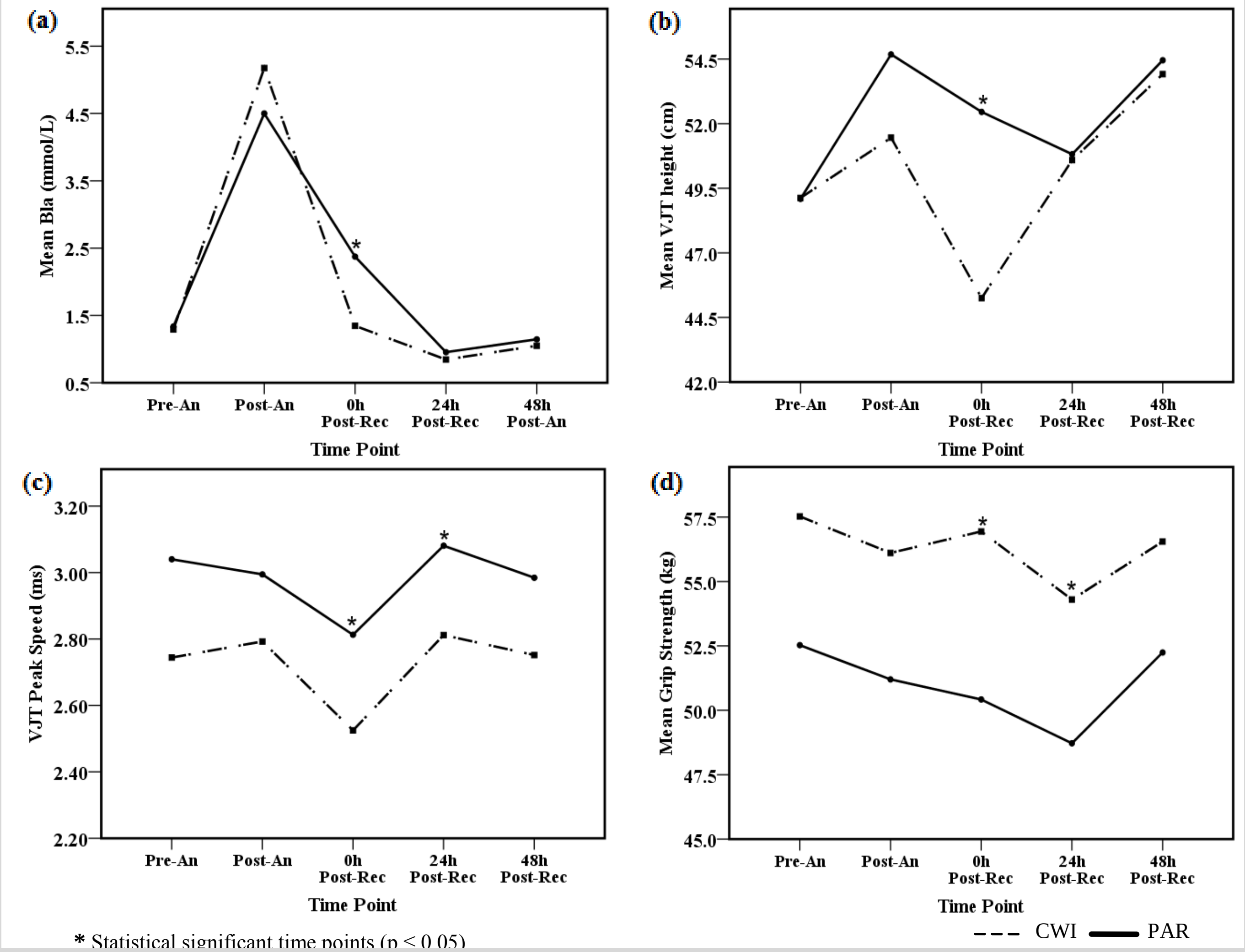


Figure 1 Intergroup results (CWI *vs.* PAR) that demonstrated significant differences over various recovery time points for (a) Mean BLa$^-$, (b) mean VJT height, (c) mean VJT peak speed and (d) mean grip strength. **(**An) = Anaerobic; (Rec) = Recovery.

Intergroup differences (CWI *vs.* PAR recovery) showed the following results with regard to the various haematological and physical measurements.

CWI vs. PAR – Haematological components: CWI as a recovery aid resulted in a statistically significant greater decrease ($F(1,21) = 5.12$; $p = 0.04$) in BLa$^-$ above the result obtained for PAR. None of the other haematological parameters demonstrated any significant differences when comparing CWI with PAR as a recovery modality.

CWI vs. PAR – Physical components: With the evaluation of the players' physical parameters a significant decrease ($F(1,21) = 6.0$; $p = 0.02$) for the CWI-group's jump height immediately following CWI recovery was noticed than was the case with PAR. Furthermore, the CWI-group's PS during the VJT significantly decreased at 0 ($F(1,21) = 4.2$, $p = 0.05$) and 24 hours ($F(1,21) = 6.2$; $p = 0.02$) compared to PAR. With regard to grip strength, the CWI-group displayed a significant increase in strength measured (kg) after the anaerobic session and at 0 hours ($F(1,21) = 6.3$; $p = 0.02$) as well as a greater increase at 24 hours ($F(1,21) = 6.6$; $p = 0.02$) following recovery than was the case with the PAR-group.

DISCUSSION

The purpose of this study was to determine the effects of CWI compared to those of PAR over a 48-hour recovery period on physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players. To the author's knowledge, this is the first study to investigate the influence of CWI and PAR as recovery modalities on various haematological and physical parameters in university-level rugby players. In addition, this is the first study to report the beneficial effect of CWI on such a wide range of parameters. To date, most studies have either not investigated a wide range of haematological parameters or have not measured both haematological and physical performance indicators in the same population.

The most important finding of the current study is the earlier convalescence to baseline levels (indicating recovery), with 3 out of the 9 variables returning at 0-hours and 5 of the 9 at 24-hours post-CWI. In contrast, the PAR-group did not demonstrate recovery in any of the variables immediately following PAR, but in 3 out of a possible 9 variables at 24 hours with an additional 2 variables showing recuperation at 48 hours.

Firstly, the wide range of haematological variables demonstrating statistical and practical significance in both the CWI and PAR-group immediately following the anaerobic session indicates that the session was sufficient to produce the desired level of fatigue elicited from training. This assumption was verified by the average BLa^- values of 4.9 $mmol.L^{-1}$ that players obtained after the execution of the anaerobic session (13). In addition, the BLa^- results revealed a statistically (for CWI) and practically significant (for CWI and PAR) decrease in BLa^- for the post-anaerobic session across all time points. Results further showed that BLa^- returned to baseline immediately after the CWI whereas immediately after PAR, BLa^- showed a 45.8% increase from baseline. These findings suggest that CWI produced a larger degree of recovery than PAR due to a significantly ($p = 0.04$) lower BLa^- level. This result is similar to the findings of Pointon and Duffield (33) who also reported a significant reduction in BLa^- after CWI compared to PAR in rugby players ($p = 0.02$). The higher lactate elimination due to CWI may be the result of increased oxidation in the skeletal muscles and the reconversion of lactate to glycogen by means of gluconeogenesis (7). Researchers also claimed that an increase in blood flow to the active skeletal muscles during CWI may also enhance lactate clearance (7). The blood flow increase might probably be caused by the increased hydrostatic pressure that will force fluids from the lower limbs up to the chest area during CWI (28,40).

CWI resulted in a larger decrease in PO_2 than in the case of PAR (13% vs. 10% respectively) at 0 hours post-intervention compared to baseline values, but the value increased significantly from 0 hours to

24 hours ($d \geq 0.8$) and 48 hours ($p \geq 0.05$) following CWI. In addition, the CWI-group had a faster return to baseline values at 24 hours compared to the PAR-group of whom values only recovered at 48 hours. These results are similar to those of Halson et al. (20) who also reported a statistically significantly lower ($p < 0.05$) PO_2 value after CWI with no influence observed on the PCO_2, HCO_3 or blood glucose levels immediately following 40-minutes of CWI. However it must be noted that haematological measures were taken from cyclists following a 40-min time trial completed in the heat. Exercise leads to an increase in the production and accumulation of CO_2, hydrogens and lactate (1). The decline in cellular PO_2 in this study may possibly be attributed to myoglobin O_2 diffuses from haemoglobin to the mitochondria (1,31). Furthermore, the lower water temperatures will lead to a reduced cardiac output and muscle blood flow, which in turn will lead to a reduction in O_2 supply to the working muscles and thereby reducing the PO_2 value for a given amount of oxygen (2). This mechanism may be partly due to the cold-shock that subjects experience during CWI, that in turn, cause an increase in pulmonary ventilation, a reduction in blood carbon dioxide levels and finally a shift in the haemoglobin dissociation curve to left (38). This shift in the curve is also related to lower temperatures, which leads to a lower alveolar PO_2 level and lower levels of haemoglobin saturation (30).

With regard to the haemoglobin values, the PAR-group showed a practically significant decrease from post-anaerobic to 0h and 48 hours post-recovery ($d \geq 0.8$) whereas no significant changes were observed for CWI over any of the time points. Furthermore, the results indicated that CWI led to a non-significant decrease in haemoglobin 0 hours post-CWI compared to both the baseline and post-anaerobic values. Similarly, the PAR-group's haemoglobin levels also decreased but recovered back to baseline values at 24 hours. Various studies examined plasma volume indirectly by measuring the changes in haemoglobin and haematocrit, and reported a decrease in plasma volume either after a 60-min or 6-hour CWI period in healthy males or combat swimmers (27,36). In addition, one of the last-mentioned studies also reported an increase in plasma volume after PAR in seven active males (36). Increased haemoglobin levels is a reflection of local muscle blood flow, vasodilatation, haemoconcentration, the effect of muscular contraction on vascular haemoglobin volume and capillary recruitment (11), which may all be related to the changes in haemoglobin levels that were observed in this study.

CWI resulted in a practically significant ($d = 1.1$) increase in plasma glucose from 0 hours to 48 hours, showing a non-statistically higher-than-baseline value at 24 and 48 hours post-recovery. Tikuisis and colleagues (37) also found increased blood glucose levels during CWI (immersed up to the neck area for the duration of 90 min) in recreational active females. The practically significant increase in blood glucose levels at 48 h may either be due to the shivering response of the body which increases the blood glucose uptake through an increase in the metabolic rate (21) or the fact that CWI does not limit blood glucose availability in the skeletal muscles (19). Similar to the CWI results, the PAR-group also obtained higher than baseline values at 24 and 48 hours in plasma glucose, but with regard to the post-anaerobic session values, it remained lower over the 48-hour period. According to Ament and Verkerke (1) exercise may lead to an increase in the consumption of nutrients such as glucose, which may lead to a decrease in blood glucose levels, possibly interfering with the functioning of the central nervous system. Both groups' blood glucose levels did however recuperate back to baseline only at 24 hours post-recovery.

With Na^+ being associated with power and strength and K^+ being more associated with a person's psychological state (impulsiveness and willingness), the decrease seen immediately following recovery in Na^+ in both groups can be expected as a result of fatigue due to the anaerobic session (41). The CWI-group demonstrated a return to the recovered state immediately after the CWI intervention. However, at 48 hours it significantly increased almost to the post-anaerobic values ($d \geq 0.8$). In contrast to these results, three studies reported no significant difference either between or after CWI in non-contact sportsmen such as swimmers, cyclists and active males amongst others (27,20,36). Indicators of inflammation in the body are either a rise in oxidation (which can be predicted by die Na^+/K^+ ratio) or a rise in aldosterone (a hormone commonly associated, and correlating negatively with Na^+ and positively with K^+) (41). Furthermore, aldosterone reduces Na^+ loss through the kidneys during vigorous training, leading to an increase in Na^+ conservation (30). In addition, two studies reported either a decrease in aldosterone and an increase in Na^+ or an increase in K^+ in male combat swimmers and active males following CWI (27,36). The results would suggest that CWI decreases the risk for inflammation, but only in cases where subjects are immersed in cold water for longer periods of time (1-6 hours) (27,36).

For the PAR-group, Na^+ revealed practical significant changes over all the time points, but more importantly sustained a practical increase from baseline, demonstrating no recovery over the 48-hour period. It can thus be concluded that the higher-than-baseline Na^+ values of both groups at all time-points following the anaerobic session was a result of either an increase in oxidation rate in the CWI-group (as a result of hyperventilation due to cold shock (38)) or a decrease in inflammation in the subjects (30).

With regard to the physical parameters, a large decrease in VJT-H of 14% was observed for the CWI-group from post-anaerobic to 0 hours post-CWI, with values increasing with 16% at 48 hours. These results were also confirmed by De Nardi et al. (12) and Delextrat et al. (10) who reported a significant decrease ($p < 0.05$) in CMJ height at 24 hours after CWI in soccer players. With regard to peak-power and peak-speed, the CWI-group only showed a practically significant decrease in VJT-PS from post-anaerobic to 0 hours post-CWI ($d = 0.8$), and then an increase to 24 hours post-CWI ($d \geq 0.8$). Therefore, CWI had a statistically less beneficial effect on VJT-H performance ($p = 0.02$) immediately after recovery compared to PAR. Furthermore, a practically significant increase for both peak-power and -speed from 0 hours to 24 hours in the PAR-group was observed. Both groups also demonstrated an increase at 24 hours compared to baseline, with CWI obtaining a larger increase in peak-power (7% *vs*. 4%) and peak speed (11% *vs*. 12%) than did PAR.

The decrease in jump performance due to CWI can be attributed to a number of possible factors, which are either related to the training session (decreased contractile force) or to the low water temperatures. A decrease in superficial tissue temperatures may have a number of physiological outcomes, such as a decrease in the nerve conduction velocity as a result of a decrease in the production of acetylcholine; a decrease in muscle spasticity and response to stretching due to a decrease in muscle spindle activity; and lastly, lower neuromuscular coordination and maximal anaerobic power (due to a positive correlation with temperature) (16,17,28).

The most important findings of the intergroup evaluations were the statistical significant differences in BLa^-, grip strength, VJT-H and VJT peak-speed at 0 and 24-hour post-recovery ($p \leq 0.05$). In this regard, CWI seems to be superior to PAR in recuperating BLa^- to baseline levels. This is in contrast to what Gregson et al. (19) and Halson et al. (20) indicated, with all reporting that no difference was found in BLa^- between CWI and PAR recovery in active males and cyclists.

When evaluating the physical parameters, the CWI-group showed a significantly lower VJT-H and slower VJT peak-speed than did PAR at 0 and 24 hours ($p \leq 0.05$), whereas grip strength values increased significantly ($p = 0.2$) from 0 hours to 24 hours for the CWI-group. Our study therefore indicates that CWI is not beneficial to VJT-H as recovery was only seen at 24 hours, compared to PAR that caused an improvement at all the time points. In contrast, Delextrat et al. (10) reported a greater jump performance in basketball players following 5 x 2-minute immersions up to the iliac crest than PAR ($p < 0.001$), whereas De Nardi et al. (12) and Pournot et al. (34) reported a smaller decrease in CMJ than in the case of PAR after immersion of 8–15 minutes in soccer, rugby, football and volleyball players. King and Duffield (29) reported a practically significant decrease in the percentage decrement in VJTH after immersion up to the iliac crest for 2 x 5-minutes separated by 2.5 minutes seated at air temperature, than was reported for PAR recovery in netball players.

In addition, the grip strength values returned to baseline values at 0 hours for the CWI-group, whereas the PAR-group only recovered at 48 hours. Both groups illustrated recovery at 24 hours with regard to VJT peak-power and peak-speed. Both the arms and hands were not immersed into the cold water during CWI which may explain the beneficial effect of CWI on grip strength. Furthermore, this beneficial effect may be from other possible internal effects taking place such as psychological mind states and haematological changes due to increased blood circulation throughout the body. Although the study only focused on the recovery after rugby simulating exercises consisting of aerobic, anaerobic and contact drills, future studies may also take into consideration the effect of opposing playing positions (forward and backline players) and evaluate the players after a full 80-minute rugby match. Furthermore, the players' anthropometric profiles may be evaluated as skinfold thickness is a good indicator of an individual's tolerance for cold exposure. Lastly, the players’ training, resting, sleeping and eating habits may be monitored in a more controlled environment to correct for the possible effect confounding variables on the recovery of team sport participants.

PRACTICAL APPLICATIONS

Firstly, the study demonstrates that CWI is adequate as a recovery intervention as it decreases blood lactate which is an indicator of fatigue and metabolic acidosis. In addition, CWI was superior to PAR as an acute recovery intervention for recuperation of BLa^- and grip strength values. Secondly, CWI was proved to be more advantageous than PAR for recovery as more variables convalesced to baseline values at 0 and 48 hours post-recovery. Auxiliary research regarding certain haematogical variables can be done to support the study's findings. Furthermore, CWI was not effective in benefitting maximal jump height performance, but was beneficial for the recovery of VJT-PS over a longer period. This recovery technique may therefore not be beneficial during a rugby match as the demands of the game require optimal strength, speed, power and aerobic and anaerobic endurance of both the lower and upper limbs. However, CWI did benefit grip strength immediately post-CWI. Thus it can be assumed that CWI up to the iliac crest with arms extended outside will benefit players more than also immersing these body parts.

REFERENCES

1. Ament, W. & Verkerke, G.J. Exercise and fatigue. *Sports Med.* 39(5): 389-422. 2009.
2. Bacher, A. Effects of body temperature on blood gases. *Intensive Care Med.* 33-36. 2006.
3. Bailey, D.M., Erith, S.J., Griffin, P.J., Dowson, A., Brewer, D.S., Gant, N. & Williams, C. Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. *J. Sport Sci.* 25(11):1163-1170. 2007.
4. Banfi, G., Melegati, G., Barrasi, A. & Melzi d'Eril, G. Beneficial effects of the whole-body cryotherapy on sport haemolysis. *J. Hum. Sport Exerc.* 4(2):189-193. 2009.
5. Brooks, J.H.M., Fuller, C.W., Kemp, S.P.T. & Reddin, D.B. Epidemiology of injuries in English professional rugby union: part 1 match injuries. *Brit. J. Sports Med*. 39(10):757-766. 2005.
6. Budziareck, M.B., Duarte, R.R.P. & Barbosa-Silva, M.C.G. Reference values and determinants for handgrip strength in healthy subjects. *Clin. Nutr.* 27(3):357-362. 2008.
7. Coffey, V., Leveritt, M. & Gill, N. Effect of recovery modality on 4-hour repeated treadmill running performance and changes in physiological variables. *J. Sci. Med. Sport*, 7(1):1-10. 2004.
8. Cohen, J. *Statistical power analysis,* (2nd ed.). Academic Press, Inc., New York. 1988.
9. Dascombe, B.J., Reaburn, P.R.J., Sirotic, A.C. & Coutts, A.J. The reliability of the i-STAT clinical portable analyser. *J. Sci. Med. Sport* 10(3):135-140. 2007.
10. Delextrat, A., Calleja-González, J., Hippocrate, A. & Clarke, N.D. Effects of sports massage and intermittent cold-water immersion on recovery from matches by basketball players. *J. Sports Sci.* 31(1):11-19. 2013.

11. DeLorey, D.S., Kowalchuk, J.M. & Paterson, D.H. Relationship between pulmonary O_2 uptake kinetics an mucle deoxygenation during moderate-intensity exercise. *J. Appl. Physiol.* 95(1):113-120. 2003.

12. De Nardi, M., La Torre, A., Barassi, A., Ricci, C. & Banfi, G. Effect of old-water immersion and contrast-water therapy after training in young soccer players. *J. Sports Med. Phys. Fitness* 51(4):609-615. 2011.

13. Deutsch, M.U., Maw, G.J., Jenkins, D. & Reaburn, P. Heart rate, blood lactate and kinematic data of elite colts (under-19) union players during competition. *J. Sports Sci*. 16(6):561-570. 1998.

14. Elias, G.P., Varley, M.C., Wyckelsma, V.L., McKenna, M.J., Minahan, C.L. & Aughey, R.J. Effects of water immersion on posttraining recovery in Australian footballers. *Int. J. Sports Physiol Perform.* 7(4):357-366. 2012.

15. Eurofit. Eurofit tests of physical fitness. 2nd Edition. Strasbourg. 1993.

16. Ferretti, G., Ishii, M., Moia, C. & Cerretelli, P. Effects of temperature on the maximal instantaneous muscle power of humans. *Eur. J. Appl. Physiol. O.* 64(2):112-116. 1992.

17. Ferretti, G. Cold and muscle performance. *Int. J. Sports Med.* 13(1):185-187. 1992.

18. Gerodimos, V. Reliability of handgrip strength test in basketball players. *J. Hum. Kinet.* 31(1):25-36. 2012.

19. Gregson, W., Allan, R., Holden, S., Phibbs, P., Doran, D., Campbell, I., Waldron, S., Hwa Joo, C. & Morton, J.P. Postexercise cold-water immersion does not attenuate muscle glycogen resynthesis. *Med. Sci. Sports Exerc.* 45(6):1174-1181. 2013.

20. Halson, S.L., Quod, M.J., Martin, D.T., Gardner, A.S., Ebert, T.R. & Laursen, P.B. Physiological responses to cold water immersion following cycling in the heat. *Int. J. Sports Physiol. Perform.* 3(3):331-346. 2008.

21. Haman, F., Péronnet, F., Kenny, G.P., Masicotte, D., Lavoie, C., Scott, C. & Weber, J. Effect of cold exposure on fuel utilization in humans: plasma glucose, muscle glycogen, and lipids. *J. Appl. Physiol.* 93(1):77-84. 2002.

22. Hamlin, M.J. The effect of contrast temperature water therapy on repeated sprint performance. *J. Sci. Med. Sport* 10(6):398-402. 2007.

23. Harman, E., Garhammer, J. & Pandorf, C. Administration, scoring and interpretation of selected tests. (*In* Beachle, T.R. *ed.* Essentials of strength training and conditioning. 2nd ed. Champaign, IL: Human Kinetics Publishers.) p. 255-257 & 287-317. 2000.

24. Hoffman, JR, Ratamess, NA, Kang, J, Rashti, SL & Faigenbaum, AD. The effects of betaine supplementation on power performance and fatigue. *J Int Soc Sports Nutr* 2009; 6(7):7-17.

25. IBM Corp. Released 2013. *IBM SPSS Statistics for Windows, Version 22.0.* Armonk, NY: IBM Corp.

26. Ingram, J., Dawson, B., Goodman, C., Wallman, K. & Beilby, J. Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. *J. Sci. Med. Sport* 12(3):417-421. 2009.

27. Jimenez, C., Regnard, J., Robinet, C., Mourot, L., Gomez-Merino, D., Chennaoui, M., Jammes, Y., Dumoulin, G., Desruelle, A. & Melin, B. Whole body immersion and hydromineral homeostasis: effect of water temperature. *Eur. J. Appl. Physiol.* 108(1):49-58. 2010.

28. Kaczmarek, M., Mucha, D. & Jarawka, N. Cold water immersion as a post-exercise recovery strategy. *Medicina sportiva*, 17(1):35-39. 2013.

29. King, M. & Duffield, R. The effects of recovery interventions on consecutive days of intermittent sprint exercise. *J. Strength Cond. Res.* 23(6): 1795-1802. 2009.

30. McArdle, W.D., Katch, F.I. & Katch, V.L. Exercise physiology: nutrition, energy and human performance. Champaign, IL: Human Kinetics, 2010.

31. Molé, P.A., Chung, Y., Tran, T.K., Sailasuta, N., Hurd, R. & Jue, T. Myoglobin desaturation with exercise intensity in human gastrocnemius muscle. *Am. J. Physiol.* 277(1):173-180. 1999.

32. Nédélec, M., McCall, A., Carling, C., Legall, F., Berthoin, S. & Dupont, G. Recovery in soccer, part 2 - Recovery strategies. *Sports Med.* 43(1):9-22. 2013.

33. Pointon, M. & Duffield, R. Cold water immersion recovery after simulated collision sport exercise. *Med. Sci. Sports Exerc.* 44(2):206-216. 2012.

34. Pournot, H., Bieuzen, F., Duffield, R., Lepretre, P.M., Cozzolino, C. & Hausswirth, C. Short term effects of various water immersions on recovery from exhaustive intermittent exercise. *J. Appl. Physio.* 111(7):1287-1295. 2011.

35. Safrit, M.J. Introduction to measurement in physical education and exercise. 2nd ed. St. Louids, MO: Times Mirror/Mosby College Publishing. 1990.

36. Stocks, J.M., Patterson, M.J., Hyde, D.E., Jenkins, A.B., Mittleman, K.D. & Taylor, N.A.S. Effects of immersion water temperature on whole-body fluid distribution in humans. *Acta physiologica scandinavica,* 182(1):3-10. 2004.

37. Tikuisis, P., Jacobs, I., Moroz, D., Vallerand, A.L. & Martineau, L. Comparison of thermoregulatory responses between men and women immersed in cold water. *J. Appl. Physiol.* 89(4):1403-1411. 2000.

38. Tipton, M.J. The initial responses to cold-water immersion in man. *Clin. Sci.* 77(6):581-588. 1989.

39. Van Wyk, D. & Lambert, M.I. Recovery strategies implemented by sport support staff of elite rugby players in South Africa. *South African journal of physiotherapy*, 65(1):41-46. 2009.

40. Wilcock, I. M., Cronin, J.B. & Hing, W.A. Physiological Response to Water Immersion A Method for Sport Recovery? *Sports Med.*, 36(9):747-765. 2006.

41. Wilson, L. The sodium/potassium ratio. 2010. Available from: http://drlwilson.com/Articles/sodium-potassium%20high.htm. Accessed: 15 July, 2014.

CHAPTER 4

4

THE EFFECT OF CONTRAST WATER THERAPY OVER A 48-HOUR RECOVERY PERIOD AFTER AN INTENSE ANAEROBIC SESSION IN A COHORT OF MALE UNIVERSITY-LEVEL RUGBY PLAYERS

(Will be submitted to: **The Journal of Science and Medicine in Sport)**

Title:

The effect of contrast water therapy over a 48-hour recovery period after an intense anaerobic session in a cohort of male university-level rugby players

Authors, names and affiliations:

Adéle Broodryk
Physical Activity, Sport and Recreation Research Focus Area
Internal box 494
Faculty of Health Sciences
North-West University
Potchefstroom
South Africa
2520
+2718 299 1804 Work
+2718 299 2022 Fax
Adele.broodryk@nwu.ac.za

Cindy Pienaar (Corresponding author)
Physical Activity, Sport and Recreation Research Focus Area
Internal box 494
Faculty of Health Sciences
North-West University
Potchefstroom
South Africa
2520
+2718 299 4284 Work
+2718 299 2022 Fax
Cindy.Pienaar@nwu.ac.za

Martinique Sparks
Physical Activity, Sport and Recreation Research Focus Area
Internal box 494
Faculty of Health Sciences
North-West University
Potchefstroom
South Africa
2520
+2718 299 1770 Work
+2718 299 2022 Fax
Martinique.Sparks@nwu.ac.za

Ben Coetzee
Physical Activity, Sport and Recreation Research Focus Area
Internal box 494
Faculty of Health Sciences
North-West University
Potchefstroom
South Africa
2520
+2718 299 1803 Work
+2718 299 2022 Fax
Ben.Coetzee@nwu.ac.za

Word Count:

Paper – 4721

Abstract – 277

Number of Tables and Figures:

Tables – 2

Figures – 1

The effect of contrast water therapy over a 48-hour recovery period after an intense anaerobic session in a cohort of male university-level rugby players

Adele Broodryk[a], Cindy Pienaar[a], Martinique Sparks[a], Ben Coetzee[a]

[a] Physical Activity, Sport and Recreation Research Focus Area; Faculty of Health Sciences, North-West University, South Africa

ABSTRACT

Objectives: The aim of the study was to determine the effect of contrast water therapy (CWT) and passive recovery (PAR) on various haematological and physical indicators.

Design: Cross-sectional, pre-post-test design.

Methods: Twenty-three rugby players were randomly assigned to either a control (PAR) or experimental (CWT) group and executed either CWT or PAR after a 15 min long anaerobic session. The CWT-group alternated between warm water (40–42°C; for 3 min), and cold water (8 ± 1°C; for 1 min), within the 20-min recovery period while the PAR-group remained seated. Haematological and physical indicators were evaluated at baseline, 3 min post-training and at 0, 24 and 48 hours post-recovery.

Results: At 0 hours, BLa^-, haemoglobin, VJT-height, VJT peak-power, VJT peak-speed and grip strength were restored to baseline, whereas plasma glucose recovered at 24 hours post-CWT. In addition, the players' jump and grip strength performance improved from baseline. The PAR-group demonstrated recovery at 0 hours in BLa^-, VJT height, VJT peak-speed and grip strength, and Na^+ and haemoglobin recovered at 24 hours and plasma glucose at 48 hours. A significant decrease ($p \leq 0.05$) was seen over time in haemoglobin and BLa^- post-anaerobic session for both groups. Significant increases were recorded in plasma glucose and PO_2 from 0 to 24 hours in both CWT and PAR groups. No significant intergroup variations were observed for any of physical components. Intergroup results indicated CWT to be superior to PAR with a significant variance between groups observed in BLa^- and grip strength (F (1,21) > 4, $p \leq 0.05$) at various time points.

Conclusion: CWT demonstrated to be superior to PAR as an acute recovery modality.

Keywords: contrast water therapy, hydrotherapy, haematological, physical, training

1. Introduction

Since 1995 the popularity and professionalism of rugby union has augmented worldwide, resulting in rapid changes of players' fitness profiles as well as in the interest of the scientific aspects of training and competition.[5,15] In the current rugby arena, players are exposed to match-play weekly for several months, increasing the demands placed on their bodies.[40]

These demands have increased the need to find a balance between match, travel and training demands along with adequate recovery interventions to maintain a high performance levels week after week.[38] In order to lessen fatigue and optimize training effects, an effective recovery session is required to repair damaged tissue, replenish depleted energy stores and remove accumulated metabolites.[24] Passive recovery (PAR) may well be the easiest intervention to apply as it entails no activity, but recovery needs to be optimised and enhanced to be beneficial for the subsequent training and competing sessions.[21] Following either 140 min of soccer-specific exercises or a 40-min cycling test completed in the heat, researchers reported a constant decrease in sprinting and jumping performance over a 24-h recovery period in male soccer players (age 15.5±1.0 yrs)[14] as well as no significant effect ($p>0.05$) over a 40-min recovery period in blood glucose, potassium (K^+), sodium (Na^+) and blood lactate (BLa^-) levels in male cyclists (age 23.8±1.6 yrs) after PAR.[22] Conversely, greater distance coverage during a sprint test over 24 hours by male rugby players following PAR was reported by Pointon and Duffield.[34]

Two popular hydrotherapy modalities utilised over the years to enhance recovery are cold water immersion (CWI) (cold water of 7–22°C) and contrast water therapy (CWT) (cold and warm water of 26-45ºC).[4,33] Webb and colleagues[42] stated that although both CWI and CWT are effective recovery techniques, CWT tends to be the most effective technique for the recovery of rugby league players. Furthermore, research clearly indicates that CWT is superior to PAR. In this regard, CWT was more effective for restoring or lowering the percentage decrease of countermovement jump (CMJ) height over a 24 h recovery period than was PAR in soccer[14], football[16] and rugby players[42]. Elias and his colleagues[16] further stated that CWT is superior to PAR with regard to CMJ performance as measured in football players after 7 cycles of 1 min warm and 1 min cold water over a 48-h recovery period. In addition, De Nardi et al.[14] reported no significant difference for haemoglobin between CWT and PAR over 24 hours; whereas Hamlin[24] observed a decrease in BLa^- after 3 min following CWT compared to active recovery in male rugby players.

CWT is the combination of cold (cold water immersion) and heat (thermotherapy), usually in an alternating manner.[26] The rational for using both cold and warm water during CWT is that the cold water would reduce the signs and symptoms of the inflammatory process and muscle spasm through vasoconstriction of the blood vessels and thereby reduce swelling and blood flow as well as oxygen utilization, tissue metabolism and metabolite production.[8,32] In contrast to this, the ultimate target of the warm water is to increase tissue temperature that would lead to vasodilatation of the blood vessels, thereby increasing blood flow, promoting muscle relaxation, reducing collagen stiffness and accelerating the metabolism and metabolite production.[7,8,32] This alternation between cold and warm water (in effect alternating between vasoconstriction and vasodilatation respectively), acts as a pumping mechanism upon the body, flushing out any accumulated metabolites.[43] Moreover, a relief of pain may be experienced due to the direct innocuous tactile stimulation of the skin, activating the thalamus and cerebral cortex which lessens the sensation of pain in the brain.[32] According to a recent review compiled by Versey, Halson and Dawson,[41] most studies immerse their participants up to the iliac crest for 1 min CWI (10–15°C) and 1–2 min hot water (38°C), alternating 3–7 cycles and accumulating 6–15 min, over an acute (0–24 hours) or chronic (24–72 hours) recovery period. Although no standard protocol exists for CWT with regard to the temperature, immersion period, total immersion period and recovery period, researchers are in agreement that if the aim is to increase blood flow (e.g. chronic condition), the intervention should end with thermotherapy, whereas ending with cold water will decreased blood flow (e.g. sub-acute phase of an injury).[26]

It is in light of the above-mentioned shortcomings and contradictions with regard to the results found and protocols used that the aim of the current study was to investigate the effect of CWT compared to PAR over a 48-h recovery period on certain physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players. This would be of benefit to sport coaches and sport scientists to optimize performance and to minimize the recovery process.

2. Methods

The specific hypothesis under scrutiny was that compared to PAR, CWT of 20-min after an intense anaerobic session will lead to a significantly ($p>0.05$) positive effect in a cohort of male university-level rugby players' physical and haematological components. Therefore a cross-sectional, pre-post-test with convenient sampling was used to test the specified hypothesis.

Twenty-three u/21 male rugby-players of a South African University's Rugby Institute voluntarily participated in the study and ethical approval was granted by the North-West University's Ethics Committee (number: NWU-00201-14-A1). The study was conducted according to the ethical guidelines and principles of the international Declaration of Helsinki and the ethical guidelines of the National Health Research Ethics Council. Regarding position, the group consisted of 13 backs (numbered nine to fifteen) and 10 forwards (numbered one to eight). The players were randomly assigned to either a control group (PAR) (n=11; age: 20.1±0.3 yrs; height: 179.7±6.7 cm; weight: 88.5±12.1 kg) or an experimental group (CWT) (n=12; age: 19.9±0.3 yrs; height: 183.2±5.8 cm; weight: 94.7±13.1 kg). Only rugby players actively involved and training as members of the Rugby Institute and totally injury free at the time of testing were eligible to participate in the study. The competitive rugby-playing experience of these players varied between 4 and 15 years with an average of 10.2±2.8 yrs.

Each subject was instructed to sleep at least 8 hours during the evening and morning prior to the testing session. They also had to abstain from ingesting any drugs and alcohol or participating in strenuous physical activity that may influence the physical or physiological responses of the body for at least 48 h before the scheduled test. This was monitored by means of a urine sample. Subjects had to maintain the same diet during the week of testing. The subjects arrived at the testing sessions in a rested and fully hydrated state. The players were tested during the in-season phase of their periodization cycle. Prior to the time of testing they had already completed three months of a combined rugby conditioning program which consisted of field training sessions five times a week and gym resistance training sessions four times a week. The field training sessions were focused on rugby-specific drills, skills and activities aimed at improving the players' fitness levels. The gym resistance training sessions focused on improving players' functional muscle strength and explosive power.

The control (PAR) and experimental (CWT) groups were subjected to a series of physical performance tests, and haematological analyses were performed at baseline (before the ingestion of breakfast), pre-anaerobic (before the anaerobic) session, post-anaerobic (3 min directly after the anaerobic training session), post-recovery (3 min directly after the recovery session), 24 h (24 h after the recovery session) and 48 h post-recovery (48 h after the recovery session).

A week before commencement of the research project the players were informed about the nature of the study, and all potential risks and benefits were explained to them. Informed consent for the investigation was also requested from the players during this session. The research project was conducted over three consecutive days for two consecutive weeks. During the first day of testing the players reported to the laboratory at 6:00 am in the morning for baseline values to be taken. The baseline testing took place in a fasting state just after players had woken up and players were afforded the opportunity of filling in the demographic and general information questionnaire. Thereafter body mass and stature were measured, followed by a blood sample collection by means of a finger prick to evaluate the lactate level and different blood variables using the i-STAT portable analyser (Abbot Point of Care Inc., Princeton, New Jersey, USA). The test subjects then performed the explosive power and hand grip strength tests without any prior warm-up period completed. Players were then allowed to eat breakfast, after which they again reported to the laboratory in groups of four players each, so that all the last-mentioned measurements could be repeated. Players were then subjected to a high-intensity anaerobic training session of 15 min. Exactly three minutes after the anaerobic session all measurements were repeated to evaluate the influence of fatigue as a result of a rugby simulating exercise session on the body. The anaerobic session was then followed by a 20-min CWT recovery session for the experimental group and 20 min of PAR for the control group. Exactly three minutes, and 24 and 48 h after completion of the different recovery techniques all the measurements were completed once again to assess the acute and long-term effects of the two recovery techniques on the different measurements.

Explosive power test: Lower body explosive power was measured by means of the Vertical Jump Test (VJT) by using a Vertex (Swift Performance Equipment, Lismore, Australia) measuring device according to the method of Harman, Garhammer and Pandorf.[25] Power output during the VJT was measured for each jump with a Tendo™ Power Output Unit (Tendo Sports Medicine, Trensin, Slovak Republic). The Tendo™ unit consisted of a transducer attached to the waist of each player measuring the linear displacement and time. Subsequently, jump velocity was calculated and power determined. Peak power output was recorded for each jump and used for the following analyses. This test has demonstrated to be a useful utility for monitoring leg power in rugby players.[15] The VJT and Tendo unit is regarded as an objective ($r\geq0.90$) and valid test ($r=0.93$) for determining the peak anaerobic power output of recreationally active participants.[27, 36] The better of two trials was recorded to the nearest 0.5 cm (the distance between adjacent vanes). The participant performed a minimum of two trials with a 30-sec rest period between each trial.

Physical performance test: Grip strength was measured by means of a hand grip dynamometer (Smedley's Dynamometer™, Tokyo). The rationale for including this test was to evaluate the central nervous system's ability to forcefully contract the forearm muscles to generate maximal force. This measurement has an interclass reliability of 0.99 for the preferred hand in team sport participants[20], and validity of 0.71 for the dominant hand.[6] The test was conducted using the Eurofit test manual[17] and two trials were allowed for the dominant hand with the best score recorded. Recording of each trial took place to the nearest kilogram and if the difference in scores was more than 3 kg, the test was repeated and the best of the three measurements used.

Blood analyses: Prior to the testing session, the i-STAT analyser was calibrated to a controlled solution according to the manufacturer's specifications by means of an electronic stimulation. The following haematological components were measured: BLa^-, PO_2, partial pressure carbon dioxide (PCO_2), total carbon dioxide (TCO_2), saturated oxygen (SO_2), HCO_3, base excess (BEx), pH, Na^+, K^+, plasma glucose, haemoglobin and haematocrit. An intra-class reliability for PO_2, PCO_2, SO_2, HCO_3, BLa^- and pH ($r=0.28$–0.95) across exercise intensities ranging from moderate to strong during either a cycling test or an intermittent running test in cyclists and recreationally active males was found by Dascombe et al.[12]

The participants were divided into their separate groups during the recovery period. The CWT participants were instructed to sit in an upright position with legs outstretched in a pool of water just above the umbilicus, with the hands and arms folded over their chests and away from the water at all times. The most commonly used ratios for the duration of warm and cold immersions have been determined as being 3:1–4:1.[26,34] The protocol required the participants to be exposed to a warm pool (40–42°C) of still water for 3 min, followed by a quick transfer within 10 sec to an adjacent cooled pool (8±1°C) of still water for 1 min.[21,35] This 4-min regimen was completed five times within the 20-min recovery period. The PAR participants were instructed to sit in a comfortable upright position in a controlled laboratory for 20 min at air temperature of ±19°C, allowing the body to recuperate without any intervention.

The Statistical Data Processing package SPSS[28] was used to process the data. Firstly, a Ward's cluster analysis was performed to determine which variables could be clustered together so that only one variable from a cluster of variables could be used for further data analysis. Next, the descriptive statistics (minimum, maximum and average) of all variables were calculated. Thirdly, a linear mixed model analysis was performed to investigate time and variable differences with an autoregressive 1 heterogeneous (AR1-Heterogeneous) structure. Players were inserted as subjects and the time points were entered as fixed effects into the model. Possible player interdependency was therefore taken into account. Lastly, between-group differences and ratio of variance in subject characteristics and variables over all the time points were examined using a one-way analysis of variance (ANOVA). The level of significance was set at $p \leq 0.05$. Effect sizes were calculated to determine practically significant differences within and between the experimental and control groups for all variables measured at different time points. Effect size (ES) (expressed as Cohen's D-value) was interpreted as following an ES of more or less 0.8 as large, an ES of more or less 0.5 as moderate and an ES of more or less 0.2 as small.[10]

Due to the fact that the results obtained from the mixed models showed no significant differences between measurements from the fasting (baseline) and non-fasting (pre-anaerobic) time points, only measurement results of the pre-anaerobic time points were used in the rest of the analyses and were referred to as the baseline values. However, it should be noted that in cases where PAR or CWT had the desired recovery effect on the different measurements of players, the post-recovery values would be similar to that of the pre-anaerobic values. This would mean that players' haematological and physical state returned to levels that were observed before the execution of a fatiguing rugby simulating exercise session. On the other hand, it is also possible that the different recovery techniques had a positive effect on some measurements by decreasing these values (such as BLa^-) from the pre-anaerobic to the post-recovery time points. *Vice versa*, recovery techniques may also lead to an increase in some measurements (such as power output during the VJT) from the one time point to the next. Therefore all of these trends in results would be an indication that the recovery techniques led to haematological and physical recovery, despite the absence of statistically or practically significant changes.

3. Results

Once the cluster analysis had been done, the following haematological variables were selected to represent the remaining variables (thus only their significance was calculated and revealed): BLa^-; PO_2; Na^+; Plasma glucose and Haemoglobin. All the physical variables were assessed for significance. The results for the effect of CWT recovery on all the haematological and physical components are presented in Table 1.

Table 1

Mean±SD values for the haematological- and physical components prior to exercise, post-anaerobic session, and at 0, 24 and 48 hours post-CWT (*n*=12).

	Time point				
Cluster reduced Haematological components	Pre-An.	Post-An.	0h Post-CWT	24h Post-CWT	48h Post-CWT
BLa^-	1.2 ± 0.4$^{a\,*}$	5.1 ± 2.3 $^{abcd*\#\blacktriangleright\phi}$	1.0 ± 0.3 $^{b\,\#}$	0.9 ± 0.3 $^{c\blacktriangleright}$	1.2 ± 0.5 $^{d\phi}$
PO_2	75.3 ± 6.6 *	74.9 ± 6.7 $^{\#}$	68.9 ± 2.6 $^{*\#\phi}$	72.6 ± 4.6	74.0 ± 3.7 $^{\phi}$
Na^+	143.1 ± 0.4	142.9 ± 0.7	142.2 ± 0.4	142.3 ± 0.6	142.8 ± 0.3
Plasma glucose	101.4 ± 3.2 *	99.6 ± 5.0 $^{\#}$	99.1 ± 5.7 $^{\blacktriangleright}$	105.6 ± 8.6	115.0 ± 12.5 $^{*\#\blacktriangleright}$
Haemoglobin	16.1 ± 1.3	16.6 ± 1.2 *	16.1 ± 1.1	16.1 ± 1.3	15.5 ± 1.0*
Remaining Haematological components					
pH	7.50 ± 0.1	7.40 ± 0.1	7.49 ± 0.1	7.47 ± 0.1	7.47 ± 0.1
PCO_2	31.6 ± 0.9	28.8 ± 0.6	31.6 ± 0.5	33.2 ± 0.5	31.2 ± 1.2
TCO_2	25.3 ±0.4	18.8 ± 0.8	24.8 ± 0.4	24.9 ± 0.4	23.8 ± 0.6
HCO_3	24.3 ± 0.3	18.1 ± 0.7	23.9 ± 0.4	24.1 ± 13.8	22.9 ± 28.5
SO_2	96.1 ± 0.4	94.8 ± 0.4	95.1 ± 0.2	95.6 ± 0.3	83.5 ± 12.5
BEx	1.0 ± 0.4	-6.7 ± 1.0	0.4 ± 0.4	0.4 ± 0.5	-1.0 ± 0.7
K^+	6.2 ± 0.3	5.2 ± 0.2	5.3 ± 0.2	5.6 ± 0.2	5.3 ± 0.2
Ca^+	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.1
Haematocrit	47.1 ± 1.0	48.8 ± 1.1	47.5 ± 1.0	47.5 ± 1.2	45.5 ± 1.4
Physical components					
VJT-H (cm)	51.1 ± 7.4	55.0 ± 7.0	51.7 ± 6.1	51.4 ± 7.5	54.6 ± 7.4
VJT-PP (W)	2642.6 ± 338.8	2771.2 ± 363.1	2803.7 ± 418.9	2646.7 ± 293.6	2710.1 ± 486.9
VJT-PS (m/s)	2.9 ± 0.3	3.0 ± 0.3	3.0 ± 0.3	2.9 ± 0.3	2.9 ± 0.2
Grip strength (kg)	54.4 ± 17.3	59.7 ± 6.1	58.9 ± 4.8	56.5 ± 5.4	58.6 ± 5.0

BEx = Base Excess; BLa- = Blood Lactate; Ca+ = Calcium; CWT = Contrast Water Therapy; HCO_3 = Bicarbonate; K+ = Potassium; Na_+ = Sodium; Pre-An = Pre-Anaerobic; Post-An = Post-Anaerobic; 0h Post-CWT = Immediately following CWT; 24h Post-CWT = 24 hours following CWT; 48h Post-CWT = 48 Hours following CWT; PCO_2 = Partial Carbon dioxide; PO_2 = Partial Oxygen; PP = Peak Power; PS = Peak Speed SO_2 = Saturated Oxygen; TCO_2 = Total Carbon dioxide; VJT = Vertical Jump Test; VJT-H = Vertical Jump Test Height.

abcd - Significant differences ($p \leq 0.05$) for corresponding letters between different time points

*** # ■ ϕ** Δ ► - Large practical significant effect ($d \geq 0.8$) for corresponding symbols between different

With regard to the influence of CWT on the haematological parameters (as seen in Table 1), a statistical significance ($p \leq 0.5$) was observed in BLa^- values from the post-anaerobic session over all the time points. However, BLa^-, PO_2 and plasma glucose showed a large practically significant effect ($d \geq 0.8$) over a variety of time points. Plasma glucose showed a large practically significant decrease ($d \geq 0.8$) over 4 time points, displaying a large practically significant increase ($d \geq 0.8$) (12–14%) at 48 h compared to all the time points except with 24 h post-CWT. The values obtained at 24 h post-CWT were the only ones to display near-baseline values over all the recovery time points, although it increased again at 48 h. PO_2 showed a similar trend over the same 4 time points, decreasing from baseline towards 0 h post-CWT (9%). Although PO_2 did not fully recover to baseline values over the 48-h period, there was a large significant increase (d=1.4) at 48 h compared to 0 h post-CWT (7%). A large significant decrease ($d \geq 0.8$) (7%) for haemoglobin was only achieved at 48 h compared to the post-anaerobic session. However compared to the baseline values; the body was already fully recuperated immediately following CWT.

Although no significance ($p \leq 0.05$) was observed in any physical variable post-CWT, all the values obtained 0 h post-CWT was improved from the baseline values. In this regard, VJT-H and grip strength improved with 7% and 8% over the 48 hours compared to baseline values.

The results for the effect of PAR on the various haematological and physical components are presented in Table 2. PAR had similar effects on BLa^- as seen with CWT regarding the practical and statistical significance, showing an improvement at 0 h compared to baseline. PO_2 resulted in a large practically significant decrease ($d \geq 0.8$) over 4 time points as well as a statistically significant decrease ($p \leq 0.05$) over 2 time points. This decrease was noticed from baseline over the 48-hour period (10–17%) and had not fully recovered to the baseline values over the time period. In addition, Na^+ resulted in a large practically significant increase over 3 time points and was fully recovered to baseline at 24 h post-PAR. Similarly, haemoglobin only fully returned to baseline at 24 h and displayed significance over 4 time points, decreasing significantly after the anaerobic session. No other haematological component demonstrated any significance over any of the time points.

Table 2

Mean±SD values for the haematological- and physical components prior to exercise, post-anaerobic session and at 0, 24 and 48 hours post-PAR (*n*=11).

	Time point				
Cluster reduced Haematological components	Pre-An.	Post-An.	0h Post-PAR.	24h Post-PAR.	48h Post-PAR.
BLa^-	2.0 ± 2.4 ^{a*}	6.6 ± 3.5 $^{abcd*\#\phi\blacktriangleright}$	1.7 ± 0.8 $^{b\,\#}$	0.9 ± 0.3 $^{c\phi}$	2.0 ± 1.5 $^{d\blacktriangleright}$
PO_2	77.3 ± 4.6 *	81.1 ± 9.6 $^{a\,\#\blacktriangleright\phi}$	69.1 ± 9.8 $^{a\,*\#}$	72.3 ± 4.3 $^{\blacktriangleright}$	74.0 ± 4.5 $^{\phi}$
Na^+	142.4 ± 0.6 *	143.5 ± 0.4	142.7 ± 0.6	142.4 ± 0.2$^{\#}$	143.6 ± 0.3 $^{*\#}$
Plasma glucose	100.6 ± 2.3	105.0 ± 4.7	96.9 ± 5.7	97.9 ± 3.7	104.4 ± 4.0
Haemoglobin	16.0 ± 0.8 *	16.7 ± 0.8 $^{*\#\blacktriangleright\phi}$	15.7 ± 0.6 $^{\#}$	16.0 ± 0.7 $^{\blacktriangleright}$	15.8 ± 0.8 $^{\phi}$
Remaining Haematological components					
pH	7.49 ± 0.1	7.39 ± 0.1	7.51 ± 0.1	7.47 ± 0.1	7.52 ± 0.1
PCO_2	31.0 ± 0.8	28.0 ± 0.8	30.6 ± 1.3	32.5 ± 0.8	31.0 ± 0.9
TCO_2	24.6 ± 0.6	17.7 ± 1.0	24.8 ± 0.5	25.4 ± 0.4	25.9 ± 0.3
HCO_3	23.8 ± 0.6	17.1 ± 1.0	23.9 ± 0.4	24.4 ± 0.4	25.0 ± 0.3
SO_2	96.3 ± 6.7	95.6 ± 0.5	94.6 ± 0.7	95.6 ± 0.3	96.1 ± 0.3
BEx	0.55 ± 0.6	-7.9 ± 1.3	0.8 ± 0.3	0.9 ± 0.5	2.1 ± 0.3
K^+	6.1 ± 0.5	5.3 ± 0.2	6.0 ± 0.5	5.6 ± 0.3	6.2 ± 0.4
Ca^+	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.1	1.2 ± 0.1
Haematocrit	47.0 ± 0.7	49.0 ± 0.7	46.5 ± 0.6	47.1 ± 0.6	46.6 ± 0.9
Physical components					
VJT-H (cm)	53.6 ± 8.6	56.8 ± 10.0	55.5 ± 8.2	55.8 ± 7.7	57.1 ± 7.7
VJT-PP (W)	2685.0 ± 769.9	2793.8 ± 319.3	2668.7 ± 265.1	2575.8 ± 296.7	2538.2 ± 385.6
VJT-PS (m/s)	3.1 ± 0.5	3.1 ± 0.5	3.1 ± 0.4	3.0 ± 0.3	2.9 ± 0.4
Grip strength (kg)	51.9 ± 5.6	54.3 ± 5.8	53.0 ±5.5	51.2 ± 6.4	52.2 ± 5.4

BEx = Base Excess; BLa- = Blood Lactate; Ca+ = Calcium; HCO_3 = Bicarbonate; K+ = Potassium; Na_+ = Sodium; PAR = Passive Recovery; Pre-An = Pre-Anaerobic; Post-An = Post-Anaerobic; 0h Post-PAR = Immediately following PAR; 24h Post-PAR = 24 hours following PAR; 48h Post-PAR = 48 Hours following PAR; PCO_2 = Partial Carbon dioxide; PO_2 = Partial Oxygen; PP = Peak Power; PS = Peak Speed; SO_2 = Saturated Oxygen; TCO_2 = Total Carbon dioxide; VJT = Vertical Jump Test; VJT-H = Vertical Jump Test Height.

abcd - Significant differences ($p \leq 0.05$) for corresponding letters between different time points

*** # ■ ϕ Δ ►** - Large practical significant effect ($d \geq 0.8$) for corresponding symbols between different

None of the physical variables were (statistically or practically) significantly influenced over the 48-h time period by PAR. Although not significant, it was observed that VJT-H improved with 6% from baseline over the full 48-h recovery period, whereas peak-speed and peak-power recovered to baseline immediately following PAR. Grip strength showed a better than baseline value at 0 h following PAR, but decreased closer to baseline values at 24 h. The intergroup (CWT *vs.* PAR) results are demonstrated in Figure 1.

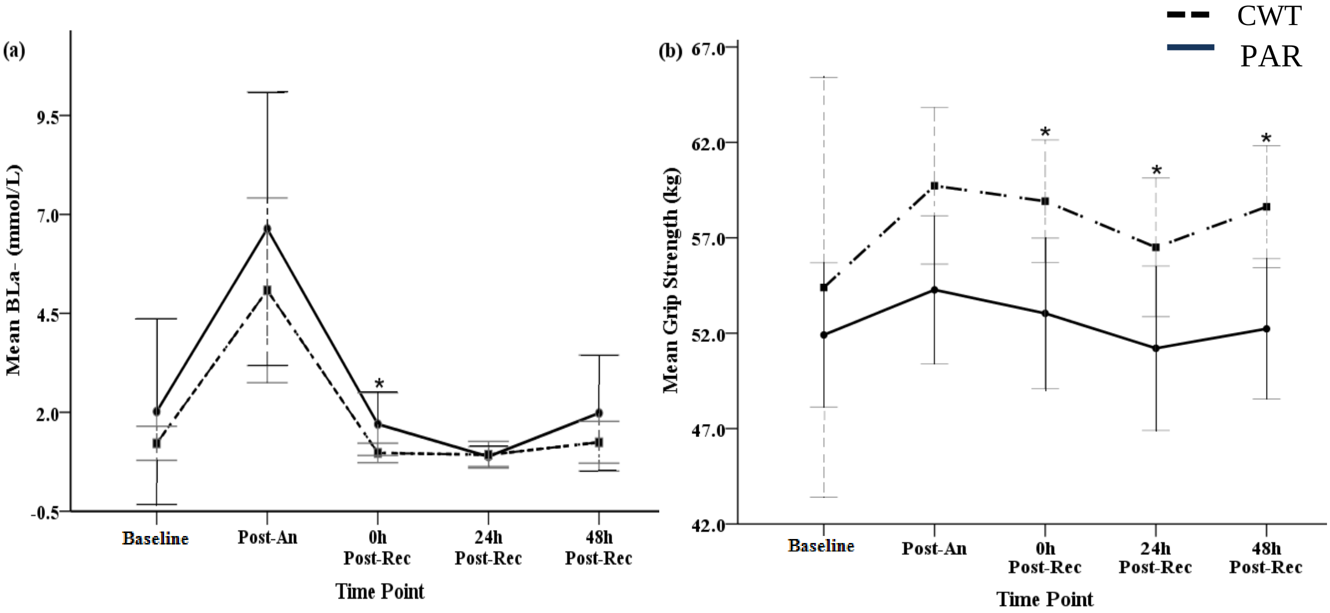


Fig. 1 Intergroup evaluations (CWT *vs.* PAR) that demonstrated significance over the various time points (An. – Anaerobic; Rec. – Recovery). ***** Indicated that CWI were significantly better than PAR results ($p \leq 0.05$)

With regard to the intergroup evaluations (Fig. 1a), the only statistically significant intergroup difference for the haematological parameters was BLa$^-$. BLa$^-$ showed a statistically and moderately practical significant decline immediately following recovery as well as a significant ratio of variance between groups ($F(1,21)=5.1$, $p=0.01$). In addition, the CWT displayed the lowest values (thus the largest recovery).

Only a single physical parameter showed a significant intergroup interaction (Fig. 1b). The grip strength results of the CWT-group displayed statistically better values than the PAR-group in strength measured (kg) after the anaerobic session ($F(1,21)=4.6$, $p=0.04$) and at 0 ($F(1,21)=6.9$, $p=0.02$), 24 ($F(1,21)=4.4$, $p=0.05$) and 48 h ($F(1,21)=8.7$, $p=0.01$) following CWT intervention.

4. Discussion

The purpose of this study was to determine the effects of CWT compared to PAR over a 48-hour period on physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players. The greatest finding from the study was the earlier return to the players' recovered state in the CWT-group. At 0 h following CWT, BLa^-, haemoglobin, VJT height, VJT peak-power, VJT peak-speed and grip strength recovered to baseline levels, whereas plasma glucose recovered at 24 h and PO_2 at 48 h post-CWT. The PAR-group demonstrated recovery to baseline in BLa^-, VJTH, VJT peak-speed and grip strength immediately following PAR, and Na^+ and haemoglobin recovered at 24 h and plasma glucose at 48 h.

A significant increase in BLa^- was seen in both groups following the intense anaerobic exercise session compared to all other time points ($p<0.05$; $d\geq0.08$), indicating that the session was adequate in producing the desired levels of fatigue and metabolic breakdown. No significant difference was observed in BLa^- for either recovery modality at any recovery time point when compared with baseline values, (thus indicating recovery). In addition, the PAR-group showed between 0-65% and the CWT-group between 0–25% lower than baseline values over all the recovery time points. These findings are in line with those of Crampton et al.[11] who monitored nine triathletes throughout two exercise bouts, (using CWT as a recovery aid alternating between 2.5 min in cold and 2.5 min in hot water between exercise bouts, for 30 min), reporting no difference in BLa^- between the two training sessions. However, two studies[29,37] reported a significantly higher BLa^- value in PAR participants varying from female netball players to male hockey-players over an 8–20 min recovery period. The results obtained for BLa^- during the intergroup evaluations are similar to those of previous studies,[9,29,37] which all reported a lower BLa^- value for CWT participants than PAR over an 8–20 min recovery period. In addition, Morton[31] reported a significantly higher rate of decrease in BLa^- after CWT than did PAR in recreational active participants indicating a greater recovery as a result of a 30-min recovery period consisting of 5 alternating cycles. This confirming evidence might either be as a result of the hydrostatic pressure, causing an inward and upward displacement of body fluids or the alterations between warm and cold water which acts as a pumping mechanism on the body.[43]

CWT resulted in a large increase in plasma glucose ($d\geq0.8$) at 24 and 48-h post-CWT compared to baseline, demonstrating a 12% increase as fatigue progressed over the time period. The PAR-group showed lower than baseline values at 0 and 24 h post-recovery, which is supported by Ament and Verkerke,[1] who stated that exercise may lead to lower blood glucose levels which may interfere with functioning of the central nervous system's functioning. Although no other studies have evaluated plasma glucose following CWT, the PAR-groups' results were similar to findings from 11 male endurance-trained cyclists.[22] However, it must be noted that the last-mentioned study measured glucose levels after the participants completed a 40-min time trial in the heat. It is therefore possible that the increase in glucose levels might be as a result of cold water immersions, as the 90-min CWI period led to an increased blood glucose level.[39] Furthermore, this significant increase in glucose levels may be partially due to an increase in blood flow and metabolite production due to warm water temperatures. Cold water immersion may also result in shivering which in turn causes an increase in the metabolic rate and glucose uptake.[7,8,23]

This observed increase in blood flow may have a subsequent effect on the O_2 supply to the muscles, due to the increased metabolic rate of oxidative phosphorylation and the elevated diffusion of O_2 from haemoglobin to the mitochondria.[30] However, Molé et al.[30] also stated that with an increase in VO_2, a decrease in PO_2 may occur due to myoglobin desaturation. In this regard, both the CWT and PAR-groups demonstrated similar trends in PO_2 changes, decreasing ($d \geq 0.08$) from baseline to post-recovery (9 and 12% respectively), and from post-anaerobic over the 48-h period. In addition, CWT showed a large increase in PO_2 (7%) from post-recovery towards the 48 h time point which may be related to the increased blood flow or due to the body's temperature returning to its normal homeostatic state. No group recuperated back to the original baseline values over the 48-h period, which means that full recovery was not attained. Bacher[2] illustrated the effect of a change in temperature on PCO_2 and PO_2, showing that with lower temperatures, PO_2 decreases while PCO_2 increases, and when temperatures rise, the opposite is noticed. It can thus be argued that our values obtained was as a result from, either an increased blood flow due to the exercise training load and warm water leading to a decreased PO_2 value, and/or a rise in temperature resulting in an increase in body temperature which lead to higher PO_2 values.

With regard to the physical measurements, the use of CWT or PAR to aid recovery from the rugby simulating exercise session did not result in any significant improvement (recovery) in any physical parameter. However, the CWT-group demonstrated better than baseline values in grip strength at all the recovery time points (PAR-group only at 2 time points). Although not significant, a lower jump height over the 24 h recovery period compared to the post-anaerobic values in both groups was observed; however all the post-recovery values were higher than the baseline values, indicating full recovery.

This is in contrast with the results of Dawson and colleagues[13] who reported significant lower than baseline values for PAR and no significant difference between PAR and CWT in football players, alternating between 5 hot and 4 cold immersions for 2 and 1 min respectively. In contrast, De Nardi and colleagues[14] reported no significant decrease for PAR but a lower decrease in CMJ for CWT (8 min period consisting of 2 min hot and cold water alterations) compared to PAR in soccer players. They contributed these to the fact that skin temperature was not significantly affected and that high environmental temperatures may have affected the measurements. Previous research[19,29,35] reported no clear difference in CMJ between PAR and CWT for various contact sport participants (netball, soccer, football, rugby and volleyball). CWT was, however, ameliorated effectively at 48 h in recovering CMJ height in football players.[16]

Grip strength showed a statistically significant effect with the intergroup evaluations at 0, 24 and 48 h following recovery ($F>4$, $p \geq 0.05$). These statistically better values for grip strength may be attributed to a number of factors: In this regard, Baker[3] stated that CWT and even thermotherapy stimulates the autonomic nervous system which changes the peripheral vasculature of the sympathetic efferent activity; whereas Cochrane[8] indicated that sympathetic nerve drive decreases. Autonomic nervous system stimulation together with constant vasodilatation and vasoconstriction of blood vessels during CWT leads to an increase in blood flow, nerve conduction velocity and reduced collagen stiffness.[7,8] In addition, an increase in hydrogens from training leads to a depression in Ca^+ uptake in the sarcoplasmic reticulum, thus decreasing the contractile force of the muscles as cross bridge interactions are inhibited.[1] Thus, it can be concluded that this improvement in grip strength may have been due to either an increased nerve conduction velocity as a result of the warm water exposure or the fact that the arms and hands were not immersed in the cold water during CWT. Only the lower extremities' that were in direct contact with the cold water should therefore show a decrease in VJT-H. Ferretti[18] stated that a muscle’s maximal anaerobic power directly correlates with the exposed temperature, which would explain why the players’ grip strength values improved but their lower body explosive power decreased.

5. Conclusion

To the authors’ knowledge, this is the first study to investigate the influence of CWT and PAR as recovery modalities on various haematological and physical components in a cohort of university-level rugby players. In addition, this is the first study to report the beneficial effects of CWT on such a wide range of parameters. To date, most studies have either not investigated a range of haematological components or have not measured both haematological and physical performance components in the specific population. Although the main focus was on the recovery after an anaerobic exercise session, future studies may take into consideration the effect of opposing playing positions (forward and backline players) and also evaluate the players after a full 80-minute rugby match. Furthermore, the players’ anthropometrical profiles may be determined as different body compositions react different to warm or cold. Lastly, external factors (training, resting, sleeping and eating habits) may be taken into consideration to correct for the possible effect of confounding variables on the recovery of team sport participants.

The study demonstrates that CWT is an adequate recovery intervention due to decreased blood lactate values (indicator of fatigue and metabolic acidosis). In addition, CWT was superior to PAR as an acute recovery intervention with regard to both BLa^- and neuromuscular recovery (grip strength values). Also, CWT was more effective as an acute recovery modality than PAR as more variables returned to their recovered state at 0 h. Although future research is needed to verify these results, coaches, sport scientists and sport related professionals can apply 20-min of CWT in order to reduce the symptoms of fatigue, enhance the recovery process either acutely (between training and playing sessions) or chronically (48-h period) and boost the performance of rugby players.

Practical Implications

- 20-min of CWT alternating between 5 cycles in warm water for 3 min and cold water for 1 min, improves BLa^- clearance immediately following recovery and BLa^- remains lower over a 24-h period.

- CWT results in an improvement in neuromuscular coordination and activation as seen in the vertical jump and grip strength tests.
- CWT is superior to PAR as more variables returned to baseline values (pre-fatigued state) at a faster rate with additional improvements over time.

Acknowledgements

No external funding was received and there are no known conflicts of interests in the preparation of this manuscript. We are very grateful to the North-West University and the u/21 rugby players together with their coaches for participating in this study. We would also like to express our sincere gratitude to all the Sport Scientists for their precious time and effort during the data collection process.

References

1. Ament, W & Verkerke, GJ. Exercise and fatigue. *Sports Med* 2009; 39(5): 389-422.
2. Bacher, A. Effects of body temperature on blood gases. *Appl Physiol Int Care Med* 2006; 31(1): 33-36.
3. Baker, PW. Is there a role for contrast hydrotherapy? *J Lymph* 2011; 6(2):72-80.
4. Breger Stanton, DE, Lazaro, R & MacDermid, JC. A systematic review of the effectiveness of contrast baths. *J Hand Ther* 2009; 22(1):57-70.
5. Brooks, JHM, Fuller, CW, Kemp, SPT & Reddin, DB. Epidemiology of injuries in English professional rugby union: part 1 match injuries. *Brit J Sports Med* 2005; 39(10):757-766.
6. Budziareck, MB, Duarte, RRP & Barbosa-Silva, MCG. Reference values and determinants for handgrip strength in healthy subjects. *Clin Nutr* 2008; 27(3):357-362.
7. Burke, DG, MacNeil, SA, Holt, LE, MacKinnon, NC & Rasmussen, RL. The effect of hot or cold water immersion on isometric strength training. *J Strength Cond Res* 2000; 14(1):21-25.
8. Cochrane, DJ. Alternating hot and cold water immersion for athlete recovery: a review. *Phys Ther Sport* 2004; 5(1):26-32.
9. Coffey, V, Leveritt, M & Gill, N. Effect of recovery modality on 4-hour repeated treadmill running performance and changes in physiological variables. *J Sci Med Sport* 2004; 7(1):1-10.
10. Cohen, J. *Statistical power analysis,* (2nd ed.). Academic Press, Inc., New York. 1988
11. Crampton, D, Donne, B, Warmington, SA & Egaña, M. Cycling time to failure is better maintained by cold than contrast or thermoneutral lower-body water immersion in normothermia. *Eur J Appl Physiol* 2013; 113(12):3059-3067.
12. Dascombe, BJ, Reaburn, PRJ, Sirotic, AC. & Coutts, A.J. The reliability of the i-STAT clinical portable analyser. *J Sci Med Sport* 2007; 10(3):135-140.

13. Dawson, B, Gow, S, Modra, S, Bishop, D & Stewart, G. Effects of immediate post-game recovery procedures on muscle soreness, power and flexibility levels over the next 48 hours. *J Sci Med Sport* 2005; (2):210-221.
14. De Nardi, M, La Torre, A, Barassi, A, Ricci, C & Banfi, G. Effect of cold-water immersion and contrast-water therapy after training in young soccer players. *J Sports Med Phys Fitness* 2011; 51(4):609-615.
15. Duthie, G, Pyne, D & Hooper, S. Applied physiology and game analysis of rugby union. *Sports Med* 2003; 33(13):973-991.
16. Elias, GP, Varley, MC, Wyckelsma, VL, McKenna, MJ, Minahan, CL & Aughey, RJ. Effects of water immersion on posttraining recovery in Australian footballers. *Int J Sports Physiol Perform* 2012; 7(4):357-366.
17. Eurofit. Eurofit tests of physical fitness. 2nd Edition. Strasbourg. 1993
18. Ferretti, G. Cold and muscle performance. *Int J Sports Med* 1992; 13(1):185-187.
19. French, DN, Thompson, KG, Garland, SW, Barnes, CA, Portas, MD, Hood, PE & Wilkes, G. The effects of contrast bathing and compression therapy on muscular performance. *Med Sci Sport Exerc* 2008; 40(7):1297-1306.
20. Gerodimos, V. Reliability of handgrip strength test in basketball players. *J Hum Kinet* 2012; 31(1):25-36.
21. Gill, ND, Beaven, CM & Cook, C. Effectiveness of post-match recovery strategies in rugby players. *Sports Med* 2006; 40(3):260-263.
22. Halson, SL, Quod, MJ, Martin, DT, Gardner, AS, Ebert, TR & Laursen, PB. Physiological responses to cold water immersion following cycling in the heat. *Int J Sports Physiol Perform* 2008; 3(3):331-346.
23. Haman, F, Péronnet, F, Kenny, GP, Masicotte, D, Lavoie, C, Scott, C & Weber, J. Effect of cold exposure on fuel utilization in humans: plasma glucose, muscle glycogen, and lipids. *J Appl Physiol* 2002; 93(1):77-84.
24. Hamlin, MJ. The effect of contrast temperature water therapy on repeated sprint performance. *J Sci Med Sport* 2007; 10(6):398-402.
25. Harman, E, Garhammer, J & Pandorf, C. Administration, scoring and interpretation of selected tests. (*In* Beachle, T.R. *ed*. Essentials of strength training and conditioning. 2nd ed. Champaign, IL: Human Kinetics Publishers.) p. 255-257 & 287-317, 2000
26. Higgins, D & Kaminski, TW. Contrast therapy does not cause fluctuations in human gastrocnemius intramuscular temperature. *J Athl Train* 1998; 33(4):336-340.
27. Hoffman, JR, Ratamess, NA, Kang, J, Rashti, SL & Faigenbaum, AD. The effects of betaine supplementation on power performance and fatigue. *J Int Soc Sports Nutr* 2009; 6(7):7-17.
28. IBM Corp. Released 2013. *IBM SPSS Statistics for Windows, Version 22.0.* Armonk, NY: IBM Corp.
29. King, M & Duffield, R. The effects of recovery interventions on consecutive days of intermittent sprint exercise. *J Strength Cond Res* 2009; 23(6):1795-1802.
30. Molé, PA, Chung, Y, Tran, TK, Sailasuta, N, Hurd, R & Jue, T. Myoglobin desaturation with exercise intensity in human gastrocnemius muscle. *Am J Physiol* 1999; 277(1):173-180.

31. Morton, RH. Contrast water immersion hastens plasma lactate decrease after intense anaerobic exercise. *J Sci Med Sports* 2007; 10(6):467-470.

32. Nadler, SF, Weingand, K & Kruse, RJ. The physiologic basis and clinical applications of cryotherapy and thermotherapy for the pain practitioner. *Pain Physician* 2004; 7(3):395-399.

33. Nédélec, M, McCall, A, Carling, C, Legall, F, Berthoin, S & Dupont, G. Recovery in soccer, part 1- Post-match fatigue and time course of recovery. *Sports Med* 2012; 42(12):997-1015.

34. Pointon, M & Duffield, R. Cold water immersion recovery after simulated collision sport exercise. *Med Sci Sports Exerc* 2012; 44(2):206-216.

35. Pournot, H, Bieuzen, F, Duffield, R, Lepretre, PM, Cozzolino, C & Hausswirth, C. Short term effects of various water immersions on recovery from exhaustive intermittent exercise. *J Appl Physiol* 2011; 111(7):1287-1295.

36. Safrit, MJ. Introduction to measurement in physical education and exercise. 2nd ed. St. Louids, MO: Times Mirror/Mosby College Publishing, 1990

37. Sayers, MG, Calder, AM & Sanders, JG. Effect of whole-body contrast-water therapy on recovery from intense exercise of short duration. *Eur J Sport Sci* 2011; 11(4):293-302.

38. Silva, R., Cleto, L., do Valle, N., Gripp, F., Rocha-Vieira, E. & Pinto, K. Effect of water immersion on post-exercise recovery from a single leg bout of aerobic exercise. *J Exerc Physiol* 2011; 14(6):47-53.

39. Tikuisis, P, Jacobs, I, Moroz, D, Vallerand, AL & Martineau, L. Comparison of thermoregulatory responses between men and women immersed in cold water. *J Appl Physiol* 2000; 89(4):1403-1411.

40. Van Wyk, D & Lambert, MI. Recovery strategies implemented by sport support staff of elite rugby players in South Africa. *South Afr J Physiother* 2009; 65(1):1-6.

41. Versey, NG, Halson, SL, Dawson, BT. Water immersion recovery for athletes: Effect on exercise performance and practical recommendations. *Sports Med* 2011; 43(11):1101-1130.

42. Webb, NP, Harris, NK, Cronin, JB. & Walker, C. The relative efficacy of three recovery modalities after professional rugby league matches. *J Strength Cond Res* 2013; 27(9):2449-2455.

43. Wilcock, IM, Cronin, JB & Hing, WA. Physiological response to water immersion: A method for sport recovery? *Sports Med* 2006; 36(9):747-765.

CHAPTER 5

[redacted]

5

SUMMARY, CONCLUSIONS, LIMITATIONS AND RECOMMENDATIONS

1. **SUMMARY**
2. **CONCLUSIONS**
3. **LIMITATIONS AND RECOMMENDATIONS**

1. SUMMARY

The purpose of this study was firstly to determine the effects of cold water immersion (CWI) compared to passive recovery (PAR) over a 48-hour period on physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players. Secondly, it was to determine the effects of contrast water therapy (CWT) compared to PAR over a 48-hour period on physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players.

Chapter 1 provided a brief summary of the problem that underlies the research questions of the study and the research questions, the objectives and hypotheses of the study as well as the structure of the dissertation. From the research question it was clear that a cross-sectional, pre-post-test with convenient sampling would be the most accurate protocol for testing the specified hypothesis. From this chapter it was clear that further research needed to be done to evaluate the effectiveness of various recovery techniques in order to minimize the recovery period and enhance the performance of athletes. The effect of various hydrotherapy recovery techniques on a wide range of haematological and physical components over a 72-hour period needs to be investigated further.

A literature review titled "Effects of various hydrotherapy recovery interventions on a variety of physical and physiological variables after strenuous training" was comprised in Chapter 2. This chapter was introduced by a brief overview of the various elements of training and recovery. Amongst this, a description of a muscle injury and how the recovery process takes place was discussed. The second aim of the introduction, provided the reader with the necessary information regarding the various factors affecting hydrotherapy and why researchers support the application thereof. The outline included the effect of hydrostatic pressure of the water, the water temperature, the duration of water immersion and lastly the effect of body composition, depth of immersion and other factors. This led to the main purpose of this chapter, namely to provide the reader with an overview of the research available regarding cold water immersion, contrast water therapy and passive recovery over a wide range of physical, physiological and psychological components over a period ranging from 0 hours to a few days. The available literature of the past 10 years (2004–2014) with regard to the study subjects, the nature of the recovery techniques implemented as well as the findings with regard to the effects of these recovery techniques on a wide variety of physical and physiological components were provided. Lastly, guidelines for the application of either recovery technique to enhance recovery and optimize sport performance were provided. From the thirty-three articles identified which investigated CWI and twenty-one regarding CWT, various results were obtained and conclusions drawn according to the effectiveness of each recovery technique.

Overall the literature supports the usage of either CWI or CWT in preference to that of PAR when the aim is have a significant physiological (to increase skin and/or rectal temperature, heart rate, sodium (Na^+), plasma glucose, and to decrease blood lactate (BLa^-), creatine kinase (CK), bicarbonate (HCO_3), partial carbon dioxide (PCO_2), heart rate, skin and/or rectal temperature), psychological (sensation of pain, muscle soreness and fatigue, increase the perception of recovery) and physical (recover and/or improve vertical jump, line-drill ability, maximal voluntary contraction (MVC) of either the knee extensors and flexors or hip muscles, maximal isometric muscle strength of the forearm flexor muscles, sprint ability, shuttle run test and cycling time trial; power output and sprint performance) difference.

However, CWI and/or CWT were not in all cases successful in bringing about more significant changes than did PAR. Physical and physiological performance components that did not obtain significant results were: heart rate, haemoglobin, haematocrit, myoglobin, lactate dehydrogenase, C-reactive protein, CK, plasma volume, BLa^-, leukocytes, platelets, reticulocytes, uric acid, testosterone, cortisol, growth hormone, prolactin, adrenaline, noradrenaline, pH levels, HCO_3, partial oxygen (PO_2), PCO_2, potassium (K^+), Na^+, rectal or skin temperature, thigh circumference, vertical jump performance, isometric strength, MVC of the quadriceps muscle, sprint times, acceleration times, agility performance, cycling performance, cycling time trial, cycling power output, perception of muscle soreness, oxygen uptake (VO_2), perceived exertion recovery and perceived muscle soreness.

Furthermore, some studies even reported a negative effect following either CWI or CWT on: countermovement jump, maximal voluntary contraction (MVC), sprinting ability, agility, cycling performance, heart rate, CK, BLa^-, plasma volume, haemoglobin and perception of muscle pain.

The recovery interventions that served as the best recovery enhancing techniques adhered to the following guidelines: Immersion up to the iliac crest for the duration of 10-minutes for the CWI subjects, whereas the participants that completed CWT were exposed for a longer period of between 12-15 minutes. Furthermore, the CWT-group completed a cold to warm water ratio of 1 min cold and 2 min warm water exposure. The participants were exposed to water temperatures that ranged from 8-12°C for the cold water and 38-40°C for the warm water.

Certain shortcomings were, however, identified during the literature review of the various recovery technique-related articles which include the following: Studies concerning CWT showed a lack in haematological components investigated; the absence of a standard protocol with regard to the water temperature, immersion period, total duration and depth of immersion; the minimal inclusion of females as participants; the absence of a refinement between males and females when both genders were included; inconsistencies regarding the population sample size (ranging from 4 to 45 participants); the absence of a familiarization and/or warm-up session prior to the measurements; the absence of a detailed description of all the methodology and variables necessary for drawing valid conclusions and lastly, inconsistencies regarding the total recovery duration. Nevertheless, the identified findings highlighted the importance, usefulness and effectiveness of either CWI or CWT as opposed to PAR to significantly improve or maintain certain physical and physiological performance components amongst the sporting fraternity.

From the available research regarding either technique, the following research questions were posed: Firstly, “What is the effect of CWI compared to that of PAR over a 48-hour recovery period on certain physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players?” Secondly, “What is the effect of CWT compared to PAR over a 48-hour recovery period on certain physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players?” These research questions were discussed in an article format in Chapter 3 and Chapter 4.

The first article was compiled in accordance with the guidelines of the Journal of Strength and Conditioning Research and titled “The effect of cold water immersion over a 48-hour recovery period after an intense anaerobic session in a cohort of male university-level rugby players” was presented in Chapter 3. The purpose of this article was to determine the effects of CWI compared to PAR over a 48-hour period on the physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players. The most important finding of the current study is the earlier convalescence to baseline levels (indicating recovery). Three (BLa^-, Na^+ and haemoglobin) out of the nine variables returned to baseline values at 0 hours, and five (PO_2, plasma glucose, vertical jump test (VJT) height, VJT peak-power, VJT peak-speed) of the nine returned at 24 hours post-CWI. In contrast to these, the PAR-group demonstrated an improvement in VJT height across all time points. However, none of the other variables recovered at 0 hours, with only three (BLa^-, haemoglobin, VJT peak-power, VJT peak-speed) recovering at 24 hours. A significant decrease ($p \leq 0.05$) was seen in VJT height, PO_2 and Na^+ from post-anaerobic to immediately following either CWI or PAR (except for VJT height). Significant increases ($p \leq 0.05$) were observed in VJT height, plasma glucose, and Na^+ from 0 hours post-recovery to 48 hours post-recovery for both CWI and PAR. PO_2 also significantly increased ($p \leq 0.05$) from 0 h to 24 and 48 hours post-CWI and for the PAR-group at 48 hours. CWI tended to have a faster recovery rate than PAR over a 24-hour period, although the same trends were observed in various components. When comparing CWI and PAR, CWI as a recovery aid resulted in a statistically significant decrease ($F = 5.12$; $p = 0.04$) in BLa^- compared to PAR. With regard to the players’ physical components, a significant decrease ($F > 4$, $p \leq 0.05$) was seen in the CWI-group’s VJT height and VJT peak speed compared to that in the PAR-group. A significant increase in grip strength was, however, noticed when comparing CWI and PAR. In conclusion, CWI tends to be more beneficial over a chronic period (24-48) hours as the body then has time to return to its normal homeostatic temperature. However, in the acute phase (0 hours) where the body is in a cooled down state, it may be detrimental on certain physical components. Furthermore, the results of this study seem to suggest that a CWI recovery session can be implemented successfully if the need is to have players recuperated within 24 hours. If, however, the goal is to recovery acutely (0 hours), the haematological components seem to respond better to CWI than to PAR. In contrast to this, the acute recovery of physical components will be better achieved with the use of PAR.

The second research question was posed in Chapter 4, which consisted of the subsequent article which was compiled in accordance with the guidelines of the Journal of Science and Medicine in Sport and titled "The effect of contrast water therapy over a 48-hour recovery period after an intense anaerobic session in a cohort of male university-level rugby players". The purpose of this article was to investigate the effect of CWT compared to PAR over a 48-hour recovery period on certain physical and haematological parameters after an intense anaerobic exercise session in a cohort of male university-level rugby players. At 0 hours, 6 variables (BLa^-, haemoglobin, VJT-height, VJT peak-power, VJT peak-speed and grip strength) were restored to baseline, whereas plasma glucose recovered at 24 hours post-CWT. In addition, the players' jump and grip strength performance improved from baseline. The PAR-group demonstrated recovery at 0 hours in 4 variables (BLa^-, VJT height, VJT peak-speed and grip strength), and 2 variables (Na^+ and haemoglobin) at 24 hours and plasma glucose at 48 hours. A significant decrease ($p \leq 0.05$) was seen in haemoglobin and BLa^- from post-anaerobic to either 24 or 48 hours for both groups. A significant increase in plasma glucose and PO_2 from 0 to 24 hours was noticed in both groups. No significant intergroup variations were observed in any physical components. However, intergroup results indicated CWT to be superior to PAR with a significant variance between groups observed in BLa^- and grip strength ($F\ (1,21) > 4$, $p \leq 0.05$) at various time points. In conclusion, CWT demonstrated to be useful as an acute recovery modality (0 hours) to mediate immediate recovery and to enhance performance as seen with the improved physical components. Additionally, if an athlete seeks to recover over a longer period (48 hours) CWT of 20 minutes would be to the advantage of the recovery and improvement of both the haematological and physical aspects of an athlete.

2. CONCLUSIONS

The conclusions drawn from this study are presented in accordance with the set hypotheses from Chapter 1:

Hypothesis 1: *CWI will have a practically significant negative effect on the vertical jump and grip strength but a statistically significant positive effect on the* BLa^-*, pH, haemoglobin, haematocrit,* Na^+*,* K^+*,* PO_2*,* PCO_2*,* HCO_3 *and base excess levels compared to PAR.*

Hypothesis 1 is partially accepted, based on the results that vertical jump height and vertical jump peak-speed showed a practically significant ($d \geq 0.8$) decrease from post-anaerobic to 0 hours following CWI. However, at 48 hours post-CWI the results showed a large practically significant increase in vertical jump from 0 hours. In contrast to this, the PAR-group showed an improved jumping performance across all time points following baseline measurement, obtaining statistically ($p \leq 0.05$) better results in the vertical jump test at 0 and 24 hours than did the CWI-group. However, a statistically significant ($p \leq 0.05$) better value was obtained in grip strength for the CWI-group compared than was the case with the PAR-group at 0 and 24 hours. Both groups demonstrated the same within-group trends with regard to all the haematological components. However, haemoglobin showed a large practically significant ($d \geq 0.8$) decrease in the PAR-group and the CWI-group a statistically significant ($p \leq 0.05$) decrease in BLa^-. Moreover, PO_2 and plasma glucose demonstrated a practically significant negative effect in the CWI-group as a decrease was observed from baseline and the post-anaerobic session over various recovery time points. However, plasma glucose increased ($p > 0.05$) above that of the baseline values at 48 hours, although a significant ($p \leq 0.05$) increase was observed when comparing the results at 48 hours with 0 and 24 hours.

Hypothesis 2: *CWT will have a practically significantly positive effect on the vertical jump and grip strength test as well as on the* BLa^-*, pH, haemoglobin, haematocrit,* Na^+*,* K^+*,* PO_2*,* PCO_2*,* HCO_3 *and base excess levels as opposed to PAR.*

Hypothesis 2 is partially accepted based on the results that the intergroup evaluations showed the grip strength values to be statistically significantly ($p \leq 0.05$) better for the CWT-group than for the PAR-group at all the recovery time points. However, none of the physical components demonstrated statistical or practical significance within either group. Both the CWT and PAR-groups demonstrated the same within-group trends with regard to the haematological components, demonstrating a significant decrease ($p \leq 0.05$) in haemoglobin and BLa^- from post-anaerobic to either 24 or 48 hours for both groups. Moreover, PO_2 showed a practically significantly ($d \geq 0.8$) negative decrease from baseline over all the recovery time points. Plasma glucose demonstrated a practically significant ($d \geq 0.8$) increase over all the time points, whereas haemoglobin practically significantly ($d \geq 0.8$) decreased at 48 hours. The intergroup results demonstrated CWT to be superior to PAR with regard to the BLa^- values, as values showed a significant decrease ($p \leq 0.05$) at 0 hours following recovery.

When the three recovery techniques are compared with one another it is clear that either CWI or CWT is superior to PAR in a cohort of male university-level rugby players. Both CWI and CWT had a wider range of variables returning to baseline levels (recovered state) at a faster rate than PAR. Furthermore, when CWI and CWT are compared regarding the various results obtained, it seems that the results favour CWT above those of CWI of 20 minutes as a recovery modality. In addition, it is frequently noticed in the sporting arena that players often participate in more than one game or tournament on a single day, imposing a great physiological demand on their bodies and a desire to enhance the recovery process in between sessions. In such instances where an athlete needs to recover immediately (0 hours), the application of CWT of 20 minutes would be the optimal recovery technique. However, in a tournament event where players play every week for several weeks and recovery is required over a longer period (24-48 hours), CWI of 20-minutes would be the recommended modality.

Furthermore, if an athlete is required to improve physical performance either over a short or long period, CWT is the most favourable modality, with explosive power and neuromuscular power amongst others. If only taking into consideration the haematological components, CWT tends to be superior to CWI at 0 hours, indicating a larger reduction in blood lactate (which is an indication of metabolic acidosis), a smaller reduction in PO_2, (the pulmonary pressure of oxygen) and a smaller reduction in plasma glucose (the amount of glucose found in the liquid part of the blood), which are all beneficial to the sporting fraternity.

However, if an athlete wishes to postpone the beneficial effects of a recovery modality (48 hours), CWI is superior to CWT. This is seen with CWI having a higher than baseline level in PO_2 (indicating a higher level of oxygen in the blood) at 48 hours, whereas CWT indicated no recovery over any time point. In addition, CWI demonstrated a closer to baseline level in haemoglobin (a red protein responsible for transporting oxygen in the blood) at 48 hours, whereas CWT indicated a lower than baseline level at this time point. If an athlete wishes to apply these methods during training, care should be taken when interpreting the haematological results, whereas the physical results are more applicable on the field.

With regard to the physical components, CWT demonstrated to be superior to CWI either over a short (0 hours) or a long period (48 hours). This was seen with an improved vertical jump height, vertical jump peak speed and grip strength results over various time points. This is beneficial, since athletes need to recover various components such as strength, power, speed, agility and/or endurance. Therefore the findings from the current study are in support of the use of 20 minutes of CWT to reduce the symptoms of fatigue in order to enhance performance in the short and long term.

3. LIMITATIONS AND RECOMMENDATIONS

The study provides support for the utilisation of either CWI or CWT recovery techniques for university-level rugby players. It was, however, also observed that not all the selected physical and haematological components were significantly influenced by the respective recovery techniques. These findings suggest that certain shortcomings need to be considered when interpreting the results of this study.

- Outliers among the rugby players that had completed their respective recovery technique could have "pulled" the ANOVA results skew due to the rather small sample size in this study. A larger sample size would therefore be advisable.
- The players were only advised on their eating, sleeping, drinking and training levels, and this may have influenced either the physical or the haematological results obtained. It could therefore be recommended that future research should clearly monitor the subject’s lifestyle and training habits in order to correct for the possible effect of confounding variables on the recovery of team sport participants.

- The players were randomly selected and not introduced to their respective recovery techniques. In some cases as seen from CWI, the cold water may serve as a shock on the players and influence the results negatively. Players can therefore be introduced to the recovery techniques beforehand in order for them to clearly know what to expect.
- The study only evaluated the acute effect over a 48 hour recovery period and not over a longer period. In view of this, research can be done to evaluate the effect over a longer recovery period, for example a week or for the duration of a full competitive season or tournament as some of the components only demonstrated significance at 48 hours.
- Research done on rugby union has demonstrated differences between playing positions. Further research may take this into consideration in providing position-based recovery techniques with regard to the immersion-duration and depth applied as forward players demonstrate a higher percentage body fat compared to that of backline players.
- Lastly, although an array of haematological components was measured, there was a lack in physical measurements taking place. More physical variables such as maximal isometric strength, aerobic and anaerobic tests which are specific to the sport, or rugby union, can therefore be made use of to gain a better understanding of changes that might take place.

In spite of the shortcomings of the study, it provides a basis for further research in the area of either cold water immersion or contrast water therapy comparing it with passive recovery, due to the fact that no other studies could be found that evaluated such a wide range of haematological variables together with physical components over a 48-hour period. According to the authors knowledge, this is the first study to report on the successful usage of 20-minutes of either cold water immersion or contrast water therapy in order to minimize the recovery period either over a short period (0 hours – 24 hours) or over a longer recovery period (48 hours) in returning variables back to their original baseline values (indicating full recovery). Moreover, the recovery techniques have demonstrated to be beneficial in order to enhance the recovery time and lessen fatigue experienced by players.

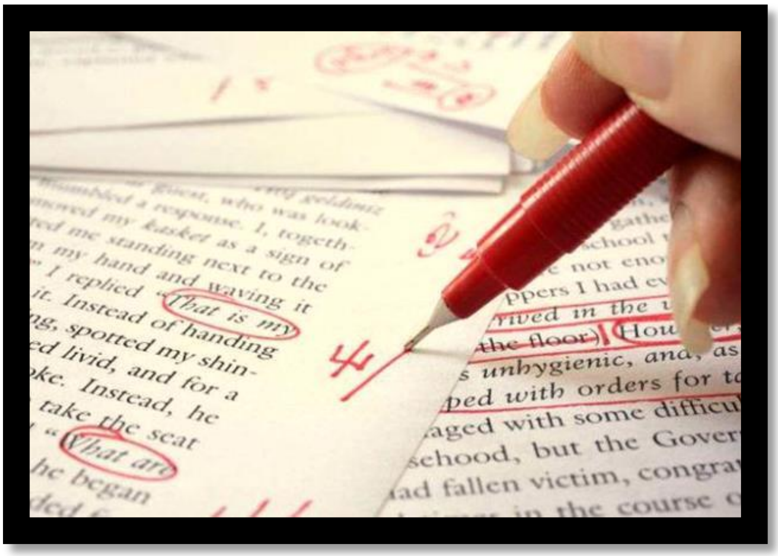
APPENDIX

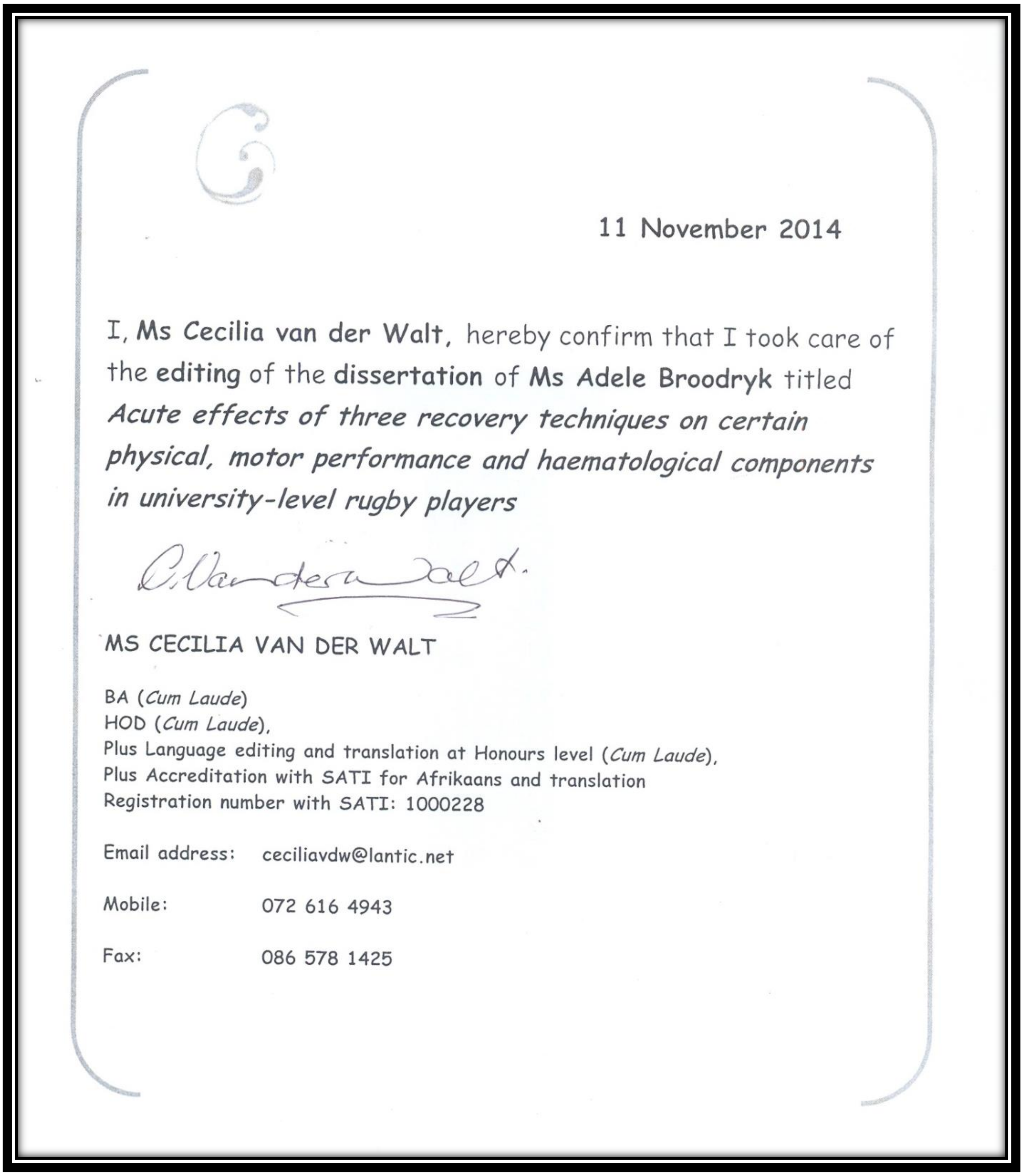
APPENDIX A, B, C, D & E

APPENDIX A	**LANGUAGE EDITING LETTER**
APPENDIX B	**GENERAL INFORMATION QUESTIONNAIRE AND INFORMED CONSENT FORMS**
APPENDIX C	**PHYSICAL ACTIVITY QUESTIONNAIRE, AND ANTHROPOMETRIC, PHYSICAL AND HAEMATOLOGICAL PERFORMANCE DATA COLLECTION FORMS**
APPENDIX D	**INSTRUCTIONS FOR AUTHORS**

APPENDIX A

LANGUAGE EDITING LETTER





11 November 2014

I, **Ms Cecilia van der Walt,** hereby confirm that I took care of the **editing** of the **dissertation** of **Ms Adele Broodryk** titled ***Acute effects of three recovery techniques on certain physical, motor performance and haematological components in university-level rugby players***

C. van der Walt

MS CECILIA VAN DER WALT

BA (*Cum Laude*)
HOD (*Cum Laude*),
Plus Language editing and translation at Honours level (*Cum Laude*),
Plus Accreditation with SATI for Afrikaans and translation
Registration number with SATI: 1000228

Email address:	ceciliavdw@lantic.net
Mobile:	072 616 4943
Fax:	086 578 1425

APPENDIX B

INFORMED CONSENT FORM, DEMOGRAPHIC AND INFORMATION QUESTIONNAIRE

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM FOR PARTICIPANTS OF THE RUGBY RECOVERY PROJECT

TITLE OF THE RESEARCH PROJECT:

Effects of different recovery techniques on certain physical, motor performance, psychological and haematological components in university-level rugby players

REFERENCE NUMBERS: NWU-00201-14-A1

PRINCIPAL INVESTIGATOR:

Prof. Ben Coetzee

ADDRESS:

School for BRS

Building K21

North-West University
Faculty of Health Sciences

Potchefstroom

2522

CONTACT NUMBER:

0182991803

You are being invited to take part in a research project that forms part of a post graduate, MA-study. Please take some time to read the information presented here, which will explain the details of this project. Please ask the researcher any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the Health Research Ethics Committee of the Faculty of Health Sciences of the North-West University (NWU-00201-14-A1 .) **and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki ad the ethical guidelines of the National Health Research Ethics Council. It might be necessary for the research ethics committee members or relevant authorities to inspect the research records.**

What is this research study all about?

- *This study will be conducted at the Potchefstroom Campus of the North-West University and will involve blood sampling, heart rate and physical activity monitoring, physical and motor performance tests, the completion of psychological questionnaires as well as a seven-day weighed food record for analyses during several time periods before and after recovery interventions. Experienced sport science researchers trained in human movement, sport science and nutrition will conduct the analyses and tests. Thirty participants will be included in this study.*
- *The objectives of this research are to determine the effects of various recovery techniques (cold water immersion (CWI), contrast water therapy (CWT), self-myofascial release and breathing techniques (SMRDB) and passive recovery (PAR)) on the lower and upper body explosive power output, forearm strength, several haematological analytes, HRV (heart rate variability), as well as certain psychological parameters iin a cohort of university-level rugby players. The researchers also want to determine If there are any statistical significant relationships between several indicators of recovery (upper body explosive power output, forearm strength, several haematological analytes, HRV as well as certain psychological parameters) in a cohort of university-level rugby players. Furthermore, another aim is to determine the effect of dietary intake on the HRV in a cohort of university-level rugby players. Moreover, the researchers want to determine the normal dietary practices, supplement use and nutritional knowledge of a cohort of university-level rugby players. The last aim is to determine the significant acute changes in certain haematological, physical, motor performance and psychological parameters after execution of a 15 minute anaerobic rugby specific session in a cohort of university-level rugby players.*

Why have you been invited to participate?

- *You have been invited to participate because you are a male u/21 rugby player from the Potchefstroom Campus of the North-West University.*
- *You have also complied with the following inclusion criteria: You are actively involved and training as a member of the Rugby Institute and are totally injury and illness free at the time of testing. Your manager and coach, and you, yourself provided voluntary consent to participate in the study.*
- *You will be excluded if: you do not attend the familiarization session; fill in all questionnaires; execute all tests, the anaerobic sessions as well as all the allocated recovery techniques.*

What will your responsibilities be?

- *You will be expected to undergo anthropometric measurements (body mass and stature), provide blood (only a finger prick) for blood analyses, complete several questionnaires and a seven-day weighed food record, execute several physical and motor performance tests: the Vertical Jump Test, the Five Repetition Smith Machine Bench Throw Test and the Grip Strength test, perform an anaerobic shuttle run session as well as various recovery techniques. These tests will be performed seven times during an one week period and will be repeated twice over another two weeks. All together all the analyses and tests will take more or less 60 minutes to perform. You will also be expected to wear a Global Positioning System and heart rate monitor during execution of the anaerobic session as well as an Actiheart monitor for 48 hours each week.*

Will you benefit from taking part in this research?

- *Among the direct benefits are that you will be able to gain access to your results. Their data will also be used to explain to you and/or your sport scientist orally which recovery techniques are more effective in causing acute physical, physiological and psychological recovery for yourself. You and your sport scientists will also be afforded the opportunity to talk to the researchers about any recovery advice that you may have a need for. Furthermore, HRV data will allow the researchers to evaluate your day to day recovery levels which can assist your coach and yourself to identify weak points and enable you to identify factors that are detrimental to your recovery. As part of the research project you will also be afforded the opportunity to obtain information with regard to your dietary preferences and profile as well as recommendations to improve your diet. Data with regard to mood states, sleeping quality and quantity will also allow researchers to provide you with feedback concerning these aspects.*
- *An indirect benefit of the study is an expansion of existing expert knowledge in the field of Applied Sport Science which can be transferred to the wider sporting community.*

Are there risks involved in your taking part in this research?

- *Risks will be minimised and the researchers will aim to maximise potential benefits that are likely to have a valuable impact on you either directly or indirectly. No severe physical, psychological, social stress or other negative consequences beyond the risks encountered in normal training are foreseen in this study. An experienced sport scientist will perform a warm before the battery of physical and motor performance tests to prepare you physically and physiologically for the test demands and to decrease injury risk. A medical doctor will be on standby during the total duration of the project, should any injuries occur. In case of illness or injury you will immediately be withdrawn from the project and will be allowed to leave at any time if they feel so.*
- *The risk for infection during blood sampling will be minimized by employing the following procedures: Before the finger prick method is employed the fingertip will be cleansed thoroughly by making use of a Webcol, alcohol swap and dried by a sterile gauze pad. The researchers who collect the blood samples will wear powder-free, sterile surgical gloves at all times during blood sampling. Gloves will replaced each time that another player's blood samples are taken. A sterile, single-use lancing device will be used to swiftly puncture the finger slightly lateral to the ball of the finger. After blood sampling the fingertip will again be cleansed by using a Webcol swap and dried by a sterile gauze pad. A sterile cotton ball will then be placed on the punctured area and closed with a hypoallergenic Band-aid adhesive bandage to stop any bleeding. All used materials (lancets, blood lactate strips, Webcols swaps, gauze pads, surgical cloves, etc.) will immediately be discarded into appropriate medical waste containers so as to minimize the risk for contact with contaminated blood. You may experience a bit of discomfort due to the finger prick technique that is used to collect venous blood. You will however be familiarized with this technique during the familiarization day a week before the project starts.*
- *Players, especially the back line players, may find the CWI uncomfortable due to the temperature of the water (8 ± 1°C) and the duration of immersion (20 minutes). You are however use to this recovery technique due to the fact that you have been subjected to it frequently during training sessions.*
- *You may also experience extreme fatigue, muscle discomfort and nausea due to execution of the anaerobic session. A scientifically compiled warm-up will however be performed before execution of the anaerobic session to minimize injury risk and to prepare the body for this session. Furthermore, you will be familiarised with the test during the familiarization session. You are however familiar with these type of interval sessions due to the fact that you regularly perform it during training.*

What will happen in the unlikely event of some form of discomfort occurring as a direct result of your taking part in this research study?

- ***Should you have the need for further discussions after the execution of the tests or analyses of matches an opportunity will be arranged for you to do so. The South African Football*** **Association** ***requires that medical staff must be available at all times during matches, which means that first aid***

personnel will be available for the duration of each match, should any injuries occur. In case of illness or injury you will immediately be withdrawn from the study and will be allowed to leave at any time if you feel so. During the execution of the physical tests a medical physician will be on standby should any medical attention be needed.

Who will have access to the data?

- *Anonymity will be partial due to the fact that the sport scientist want feedback with regard to the outcome of the different recovery techniques but the researchers will respect the decision of each player in order to protect his anonymity. Data will be coded to ensure that no link can be made to a specific player. Reporting of findings will be anonymous by only authorising the head researcher to have control over the distribution of these findings. Only the head researcher and research assistants will have access to the data and will also sign a confidentiality agreement to protect players. Data will be kept safe and secure by locking hard copies in locked cupboards in the researcher's office and for electronic data it will be password protected. Data will be stored for 7 years.*

Will you be paid to take part in this study and are there any costs involved?

No, you will not be paid to take part in the study. There will also be no costs involved for you, if you do take part.

Is there anything else that you should know or do?

- **You can contact** Prof Ben Coetzee **at** 018 299 1803**;** ben.coetzee@nwu.ac.za **if you have any further queries or encounter any problems.**
- **You can contact the Health Research Ethics Committee via Mrs Carolien van Zyl at 018 299 2094; carolien.vanzyl@nwu.ac.za if you have any concerns or complaints that have not been adequately addressed by the researcher.**
- **You will receive a copy of this information and consent form for your own records.**

How will you know about the findings?

- **The findings of the research will be shared with you if you are interested. You are welcome to contact us regarding the findings of the research. We will be sharing the findings with you as soon as it is available**

Declaration by participant

By signing below, I …………………………………..…………. agree to take part in a research study entitled: **Effects of different recovery techniques on certain physical, motor performance, psychological and haematological components in university level rugby players.**

I declare that:

- I have read this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions to both the person obtaining consent, as well as the researcher and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ....…........……………... on (*date*) …………....……….. 20....

....	....
Signature of participant	Signature of witness

Declaration by person obtaining consent

I *(name)* ………………………………………….………. declare that:

- I explained the information in this document to …………………………………..
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use a interpreter.

Signed at (*place*) ....…......……………….. on (*date*) …………...……….. 20....

……………………………………………………………………… ………………………………………………………………………

Signature of person obtaining consent Signature of witness

Declaration by researcher

I *(name)* ………………………………………….………. declare that:

- I explained the information in this document to …………………………………..
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use a interpreter.

Signed at (*place*) ....…......……………….. on (*date*) …………...……….. 20....

……………………………………………………………………… ………………………………………………………………………

Signature of researcher **Signature of witness**

PhASRec PHYSICAL ACTIVITY, SPORT & RECREATION | NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

General Demographic and Information Questionnaire for the Rugby Recovery Project

GENERAL INFORMATION

Please write clearly!

1. GEOGRAPHICAL INFORMATION

1.1 Surname: **Initials** **First Name**

1.2 Age:

Years:	Months:

1.3 Birth date:

Year:	Month:	Day:

1.4 Permanent residential address in South Africa:

____

____

____

____

____

1.5 Permanent postal address in South Africa:

____

____

____

____

____

____

____

1.6 Phone numbers:

Home:	Work:
Fax:	Cell:
E-mail:	

1.7 Ethnic group

White	Coloured	Black	Indian

In the next few question cross out the answers that are applicable to you!!

2. INFORMATION REGARDING TRAINING HABITS

2.1 Years you've been playing rugby - since you started to specialise in rugby.

1-2 years	3-4 years	5-6 years	7-8 years	8-9 years	10-11 years	12 or more

2.2 Frequency of training - how many days per week do you normally train?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.3 Frequency of training - how many <u>days per week</u> do you normally do weight training?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.4 Frequency of training - how many <u>days per week</u> do you normally have field sessions?

1 day	2 days	3 days	4 days	5 days	6 days	7 days

2.5 How many <u>hours per day</u> do you normally train?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.6 How many <u>hours per day</u> do you normally spend on weight training?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.7 How many <u>hours per day</u> do you normally spend on training on the field?

1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 or more

2.8 Do you spend any time on psychological preparation for rugby and competitions?

Never	*Sometimes	*Often	*Always

*** Please specify the type of psychological preparation you do if you marked any of these three options:**

____

____

____

____

____

____

____

3. MEDICAL INFORMATION

3.1 Please describe any past or current musculoskeletal conditions you have incurred (i.e., muscle pulls, sprains, fractures, surgery, back pain, or any general discomfort):

Head/Neck:

____
____
____
____

Shoulder/Clavicle:

____
____
____
____
____

Arm/Elbow/Wrist/Hand:

____
____
____
____
____

Back:

____
____
____
____

Hip/Pelvis:

____
____
____
____

Thigh/Knee:

____
____
____
____
____

Lower leg/Ankle/Foot:

____
____
____

3.2 Please list any medication being taken currently and/or taken during the last year:

____
____
____
____
____

3.3 List any other illness or disorder that a physician has told you of:

____
____
____

____

____

4. COMPETITION DATA

4.1 At what level are you competing this year?

____

4.2 What is the highest level that you competed at last year?

Club:	Provincial:	National:	International:

4.3 How many matches, approximately, have you played?

Club:	Provincial/National:

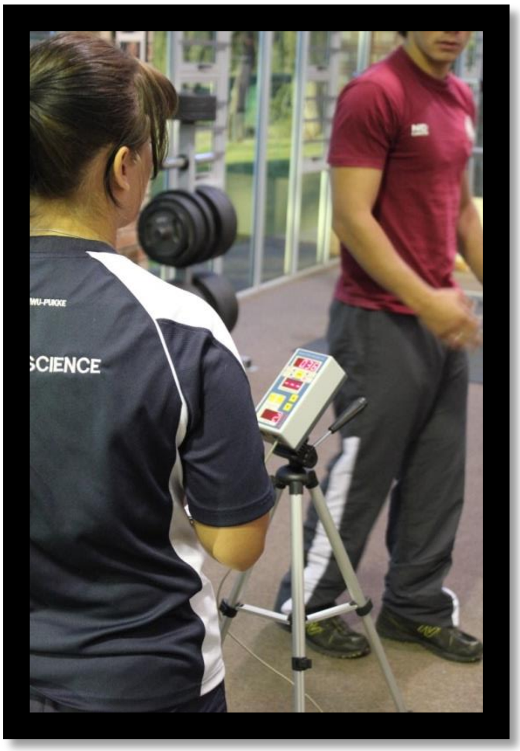
4.4 What were the highest achievements you attained the past two years?

Achievement	Competition	Date

4.5 What position/s do you usually play during matches?

1.
2.
3.

APPENDIX C ANTHROPOMETRIC, PHYSICAL AND HAEMATOLOGICAL PERFORMANCE DATA COLLECTION FORMS



PhASRec PHYSICAL ACTIVITY, SPORT & RECREATION | NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
POTCHEFSTROOM CAMPUS

RAW DATA FOR HRV – NAME OF PLAYER AND NUMBER: ________________________

Recovery group: CWI / CWT or PAR (encircle the relevant option)

TIME POINT (BASELINE, PRE-ANAEROBIC, POST-ANAEROBIC, 0-HOURS POST RECOVERY, 24-HOURS POST RECOVERY, 48-HOURS POST RECOVERY OR 72-HOURS POST RECOVERY)	
TEST COMPONENT	**1ST TIME**
BODY MASS (KG)	
BODY STATURE (CM)	
LACTATE	
PCO_2	
PO_2	
TCO_2	
HCO_3	
BASE EXCESS	
SO_2	
Na	
K	
Ca	
PLASMA GLUCOSE	
HEMATOCRIT	
HEMOGLOBIN	
PH	
HRV	

TIME OF HRV (H:MIN:SEC)	
TEST COMPONENT	**1ST TIME**
VERTEX POLE HEIGHT – REACHING (CM)	
VERTICAL JUMP REACHING HEIGHT (CM)	A
VERTEX POLE HEIGHT – JUMPING (CM)	

TEST COMPONENT	**1ST READING**	**2ND READING**	**HIGHEST**
VERTICAL JUMP HEIGHT (CM)			
FINAL VERTICAL JUMP HEIGHT A-B (CM)			
TENDO PEAK POWER (W)			
TENDO SPEED (M/SEC)			

TEST COMPONENT	**1ST READING**	**2ND READING**	**HIGHEST**
BENCH THROWS TEST PEAK POWER (W)			
BENCH THROWS TEST SPEED (M/SEC)			

TEST COMPONENT	**1ST**	**2ND**	**3rd**	**4th**	**5th**
BENCH AVERAGE POWER (W) (1ST ATTEMPT)					

BASE LINE TEST (TUESDAY MORNING)

TEST COMPONENT	**1ST**	**2ND**	**3rd**	**4th**	**5th**
BENCH AVERAGE POWER (W) (2ND ATTEMPT)					

TEST COMPONENT	**1ST READING**	**2ND READING**	**HIGHEST**
GRIP STRENGTH (KG)			

THE STELLENBOSCH MOOD SCALE

Name and Surname:		**Date and time:**	

Below is a list of words that describe feelings people have. Please read each one carefully. Mark [X] the answer that best describes **how you feel right now**. / *Hieronder is 'n lys van woorde wat gevoelens beskryf wat mense ervaar. Lees asseblief elkeen noukerig en merk [X] die antwoord wat die beste beskryf* ***hoe jy op hierdie oomblik voel****.*

AFRIKAANS	*Gladnie* / Not at all	*Effens* / A little	*Taamlik* /Moderately	*Baie* / Quite a bit	*Uiters* / Extremely	**ENGLISH**
Verward	☐	☐	☐	☐	☐	**Confused**
Vermoeid	☐	☐	☐	☐	☐	**Worn out**
Vererg	☐	☐	☐	☐	☐	**Annoyed**
Verbitterd	☐	☐	☐	☐	☐	**Bitter**
Vaak	☐	☐	☐	☐	☐	**Sleepy**
Uitgeput	☐	☐	☐	☐	☐	**Exhausted**
Senuweeagtig	☐	☐	☐	☐	☐	**Nervous**
Paniekerig	☐	☐	☐	☐	☐	**Panicky**
Op en wakker	☐	☐	☐	☐	☐	**Alert**
Ontwrig	☐	☐	☐	☐	☐	**Muddled**
Onseker	☐	☐	☐	☐	☐	**Uncertain**
Ongelukkig	☐	☐	☐	☐	☐	**Unhappy**
Neerslagtig	☐	☐	☐	☐	☐	**Depressed**
Moeg	☐	☐	☐	☐	☐	**Tired**
Mismoedig	☐	☐	☐	☐	☐	**Downhearted**

Lewendig	☐	☐	☐	☐	☐	**Lively**
Kwaad	☐	☐	☐	☐	☐	**Angry**
Humeurig	☐	☐	☐	☐	☐	**Bad tempered**
Energiek	☐	☐	☐	☐	☐	**Energetic**
Ellendig	☐	☐	☐	☐	☐	**Miserable**
Deurmekaar	☐	☐	☐	☐	☐	**Mixed up**
Bekommerd	☐	☐	☐	☐	☐	**Worried**
Angstig	☐	☐	☐	☐	☐	**Anxious**
Aktief	☐	☐	☐	☐	☐	**Active**

RESTQ-52 SPORT

This questionnaire consists of a series of statements. These statements possibly describe your psychic or physical well-being or your activities during the past few days and nights.

Please select the answer that most accurately reflects your thoughts and activities. Indicate how often each statement was right in your case in the past days.

The statements related to performance should refer to performance during competition as well as during practice.

Please do not leave any statement blank.

Example:

In the past 3 days/nights

…I read the newspaper

0	**1**	**2**	**3**	**4**	[✓ **5**]	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	[✓ **Very often**]	**Always**

In this example, the number 5 is marked. This means that you read a newspaper very often in the past three days.

In the past 3 days/nights…

1) … I watched TV

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

2) … I laughed

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

3) … I was in a bad mood

0	**1**	**2**	**3**	**4**	**5**	**6**

Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

4) … I felt physically relaxed

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

In the past 3 days/nights …

5) … I was in good spirits

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

6) … I had difficulties in concentrating

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

7) … I worried about unresolved problems

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

8) … I had a good time with my friends

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

9) … I had a headache

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

10) … I was dead tired after work/class

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

11) … I was successful in what I did

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

12) … I felt uncomfortable

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

In the past 3 days/nights…

13) … I was annoyed by others

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

14) … I felt down

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

15) … I had a satisfying sleep

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

16) … I was fed up with everything

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

17) … I was in a good mood

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

18) … I was overtired

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

19) … I slept restlessly

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

20) … I was annoyed

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

In the past 3 days/nights…

21) … I felt as if I could get everything done

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

22) … I was upset

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

23) … I put off making decisions

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

24) … I made important decisions

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

25) … I felt under pressure

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

26) … parts of my body were aching

0	**1**	**2**	**3**	**4**	**5**	**6**

Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

27) … I could not get rest during the breaks

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

28) … I was convinced I could achieve my set goals during performance

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

In the past 3 days/nights…

29) … I recovered well physically

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

30) … I felt burned out by my sport

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

31) … I accomplished many worthwhile things in my sport

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

32) … I prepared myself mentally for performance

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

33) … my muscles felt stiff or tense during performance

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

34) … I had the impression there were too few breaks

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

35) … I was convinced that I could achieve my performance at any time

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

36) … I dealt very effectively with my teammates' problems

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

In the past 3 days/nights…

37) … I was in a good condition physically

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

38) … I pushed myself during performance

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

39) … I felt emotionally drained from performance

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

40) … I had muscle pain after performance

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

41) … I was convinced that I performed well

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

42) … too much was demanded of me during the breaks

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

43) … I psyched myself up before performance

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

44) … I felt that I wanted to quit my sport

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

In the past 3 days/nights …

45) … I felt very energetic

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

46) … I easily understood how my teammates felt about things

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

47) … I was convinced that I had trained well

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

48) … the breaks were not at the right times

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

49) … I felt vulnerable to injuries

0	**1**	**2**	**3**	**4**	**5**	**6**

Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

50) … I set definite goals for myself during performance

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

51) … my body felt strong

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

52) … I felt frustrated by my sport

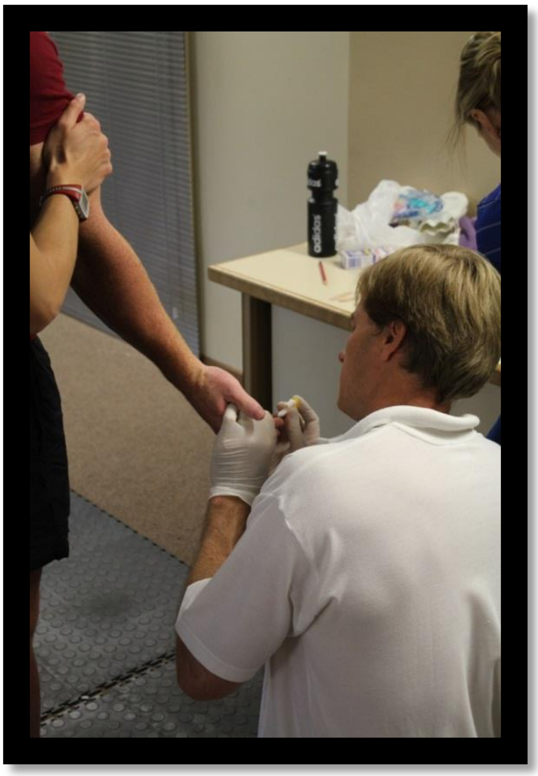
0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

53) … I dealt with emotional problems in my sport very calmly

0	**1**	**2**	**3**	**4**	**5**	**6**
Never	**Seldom**	**Sometimes**	**Often**	**More often**	**Very often**	**Always**

END

APPENDIX D INSTRUCTIONS FOR AUTHORS



MANUSCRIPT SUBMISSION GUIDELINES

Manuscripts may be submitted on-line at http://www.editorialmanager.com/JSCR or by email following the instructions below. When submitting by email, only one copy is required of each document including a copyright form.

1. If by email, authors should submit a MicrosoftWord (.doc) file.

2. A cover letter must accompany the manuscript and state the following: ''This manuscript is original and not previously published, nor is it being considered elsewhere until a decision is made as to its acceptability by the JSCR Editorial Review Board.'' Please include the corresponding author's full contact information, including address, email, and phone number.

3. All authors should be aware of the publication and be able to defend the paper and its findings and should have signed off on the final version that is submitted. For additional details related to authorship, see ''Uniform Requirements for Manuscripts Submitted to Biomedical Journals'' at http://www.icmje.org/.

4. The NSCA and the Editorial Board of the JSCR have endorsed the American College of Sports Medicine's policies with regards to animal and human experimentation. Their guidelines can be found online at http://www.editorialmanager.com/msse/. Please read these policies carefully. Each manuscript must show that they have had Institutional Board approval for their research and appropriate consent has been obtained pursuant to law. All manuscripts must have this clearly stated in the methods section of the paper or the manuscript will not be considered for publication.

5. All manuscripts must be double-spaced with an additional space between paragraphs. The paper should include a minimum of 1-inch margins and page numbers in the upper right corner next to the running head. Authors must use terminology based upon the International System of Units (SI). A full list of SI units can be accessed online at http://physics.nist.gov/.

6. The JSCR endorses the same policies as the American College of Sports Medicine in that the language is English for the publication. ''Authors who speak English as a second language are encouraged to seek the assistance of a colleague experienced in writing for English language journals.

Authors are encouraged to use nonsexist language as defined in the American Psychologist 30:682-684, 1975, and to be sensitive to the semantic description of persons with chronic diseases and disabilities, as outlined in an editorial in Medicine & Science in Sports & Exercise_, 23(11), 1991. As a general rule, only standardized abbreviations and symbols should be used. If unfamiliar abbreviations are employed, they should be defined when they first appear in the text. Authors should follow Webster's Tenth Collegiate Dictionary for spelling, compounding, and division of words. Trademark names should be capitalized and the spelling verified. Chemical or generic names should precede the trade name or abbreviation of a drug the first time it is used in the text.''

7. There is no word limitation but authors are instructed to be concise and accurate in their presentation and length will be evaluated by the Editor and reviewers for appropriateness.

MANUSCRIPT PREPARATION

1. Title Page

The title page should include the manuscript title, brief running head, laboratory(s) where the research was conducted, authors' full name(s) spelled out with middle initials, department(s), institution(s), full mailing address of corresponding author including telephone and fax numbers, and email address, and disclosure of funding received for this work from any of the following organizations: National Institutes of Health (NIH); Wellcome Trust; Howard Hughes Medical Institute (HHMI); and other(s).

2. Blind Title Page

A second title page should be included that contains only the manuscript title. This will be used to send to the reviewers in our double blind process of review. Do not place identifying information in the Acknowledgement portion of the paper or anywhere else in the manuscript.

3. Abstract and Key Words

On a separate sheet of paper, the manuscript must have an abstract with a limit of 250 words followed by 3 – 6 key words not used in the title. The abstract should have sentences (no headings) related to the purpose of the study, brief methods, results, conclusions and practical applications.

4. Text

The text must contain the following sections with titles in ALL CAPS in this exact order:

A. Introduction. This section is a careful development of the hypotheses of the study leading to the purpose of the investigation. In most cases use no subheadings in this section and try to limit it to 4 – 6 concisely written paragraphs.

B. Methods. Within the METHODS section, the following subheadings are required in the following order: ''Experimental Approach to the Problem,'' where the author(s) show how their study design will be able to test the hypotheses developed in the introduction and give some basic rationales for the choices made for the independent and dependent variables used in the study; ''Subjects,'' where the authors include the Institutional Review Board or Ethics Committee approval of their project and appropriate informed consent has been gained. All subject characteristics that are not dependent variables of the study should be included in this section and not in the RESULTS; ''Procedures,'' in this section the methods used are presented with the concept of ''replication of the study'' kept in mind. ''Statistical Analyses,'' here is where you clearly state your statistical approach to the analysis of the data set(s). It is important that you include your alpha level for significance (e.g., P # 0.05). Please place your statistical power in the manuscript for the n size used and reliability of the dependent measures with intra-class correlations (ICC Rs). Additional subheadings can be used but should be limited.

C. Results. Present the results of your study in this section. Put the most important findings in Figure or Table format and less important findings in the text.Do not include data that is not part of the experimental design or that has been published before.

D. Discussion. Discuss the meaning of the results of your study in this section. Relate them to the literature that currently exists and make sure you bring the paper to completion with each of your hypotheses. Limit obvious statements like, ‛‛more research is needed.’’

E. Practical Applications. In this section, tell the ‛‛coach’’ or practitioner how your data can be applied and used. It is the distinctive characteristic of the JSCR and supports the mission of ‛‛Bridging the Gap’’ for the NSCA between the laboratory and the field practitioner.

5. References

All references must be alphabetized by surname of first author and numbered. References are cited in the text by numbers [e.g., (4,9)]. All references listed must be cited in the manuscript and referred to by number therein. For original investigations, please limit the number of references to fewer than 45 or explain why more are necessary. The Editorial Office reserves the right to ask authors to reduce the number of references in the manuscript. Please check references carefully for accuracy. Changes to references at the proof stage, especially changes affecting the numerical order in which they appear, will result in author revision fees. End Note Users: The Journal of Strength & Conditioning Research reference style ,ftp://support.isiresearchsoft.com/ pub/pc/styles/endnote4/J Strength Condition Res.ens. may be downloaded for use in the End Note application: ftp:// support.isiresearchsoft.com/pub/pc/styles/endnote4/J%20 Strength%20Condition%20Res.ens.

Below are several examples of references:

Journal Article
Hartung, GH, Blancq, RJ, Lally, DA, and Krock, LP. Estimation of aerobic capacity from submaximal cycle ergometry in women. Med Sci Sports Exerc 27: 452–457, 1995.

Book
Lohman, TG. Advances in Body Composition Assessment. Champaign, IL: Human Kinetics, 1992.

Chapter in an edited book
Yahara, ML. The shoulder. In: Clinical Orthopedic Physical Therapy. J.K. Richardson and Z.A. Iglarsh, eds. Philadelphia: Saunders, 1994. pp. 159–199.

Software
Howard, A. Moments ½software_. University of Queensland, 1992.

Proceedings
Viru, A, Viru, M, Harris, R, Oopik, V, Nurmekivi, A, Medijainen, L, and Timpmann, S. Performance capacity in middle-distance runners after enrichment of diet by creatine and creatine action on protein synthesis rate. In: Proceedings of the 2nd Maccabiah-Wingate International Congress of Sport and Coaching Sciences. G. Tenenbaum and T. Raz-Liebermann, eds. Netanya, Israel, Wingate Institute, 1993. pp. 22–30.

Dissertation/Thesis
Bartholmew, SA. Plyometric and vertical jump training.Master’s thesis, University of North Carolina, Chapel Hill, 1985.

6. Acknowledgments

In this section you can place the information related to Identification of funding sources; Current contact information of corresponding author; and gratitude to other people involved with the conduct of the experiment. In this part of the paper the conflict of interest information must be included. In particular, authors should: 1) Disclose professional relationships with companies or manufacturers who will benefit from the results of the present study, 2) Cite the specific grant support for the study and 3) State that the results of the present study do not constitute endorsement of the product by the authors or the NSCA. Failure to disclose such information could result in the rejection of the submitted manuscript.

7. Figures

Figure legends should appear on a separate page, with each figure appearing on its own separate page. One set of figures should accompany each manuscript. Use only clearly delineated symbols and bars. Please do not mask the facial features of subjects in figures. Permission of the subject to use his/her likeness in the Journal should be included in each submission.

Electronic photographs copied and pasted into Word and PowerPoint will not be accepted. Images should be scanned at a minimum of 300 pixels per inch (ppi). Line art should be scanned at 1200 ppi. Please indicate the file format of the graphics.We accept TIFF or EPS format for both Macintosh and PC platforms.We also accept image files in the following Native Application File Formats:
_ Adobe Photoshop (.psd)
_ Illustrator (.ai)
_ PowerPoint (.ppt)
_ QuarkXPress (.qxd)

If you will be using a digital camera to capture images for print production, you must use the highest resolution setting option with the least amount of compression. Digital camera manufacturers use many different terms and file formats when capturing high-resolution images, so please refer to your camera's manual for more information.

Placement:. Make sure that you have cited each figure and table in the text of the manuscript. Also show where it is to be place by noting this between paragraphs, such as Figure 1 about here or Table 1 about here.

Color figures: The journal accepts color figures for publication that will enhance an article. Authors who submit color figures will receive an estimate of the cost for color reproduction in print. If they decide not to pay for color reproduction in print, they can request that the figures be converted to black and white at no charge. All color figures can appear in color in the online version of the journal at no charge (Note: this includes the online version on the journal website and Ovid, but not the iPad edition currently)

8. Tables

Tables must be double-spaced on separate sheets and include a brief title. Provide generous spacing within tables and use as few line rules as possible. When tables are necessary, the information should not duplicate data in the text. All figures and tables must include standard deviations or standard errors.

9. Supplemental Digital Content (SDC)

Authors may submit SDC via Editorial Manager to LWW journals that enhance their article's text to be considered for online posting. SDC may include standard media such as text documents, graphs, audio, video, etc. On the Attach Files page of the submission process, please select Supplemental

Audio, Video, or Data for your uploaded file as the Submission Item. If an article with SDC is accepted, our production staff will create a URL with the SDC file. The URLwill be placed in the call-out within the article. SDC files are not copy-edited by LWW staff, they will be presented digitally as submitted. For a list of all available file types and detailed instructions, please visit http://links.lww.com/A142.

SDC Call-outs

Supplemental Digital Content must be cited consecutively in the text of the submitted manuscript. Citations should include the type of material submitted (Audio, Figure, Table, etc.), be clearly labeled as ‟Supplemental Digital Content,'' include the sequential list number, and provide a description of the supplemental content. All descriptive text should be included in the call-out as it will not appear elsewhere in the article.
Example:
We performed many tests on the degrees of flexibility in the elbow (see Video, Supplemental Digital Content 1, which demonstrates elbow flexibility) and found our results inconclusive.

List of Supplemental Digital Content

A listing of Supplemental Digital Content must be submitted at the end of the manuscript file. Include the SDC number and file type of the Supplemental Digital Content. This text will be removed by our production staff and not be published.
Example:
Supplemental Digital Content 1. wmv

SDC File Requirements

All acceptable file types are permissible up to 10 MBs. For audio or video files greater than 10 MBs, authors should first query the journal office for approval. For a list of all available file types and detailed instructions, please visit http://links.lww.com/A142.

AUTHOR FEES

JSCR does not charge authors a manuscript submission fee or page charges. However, once a manuscript is accepted for publication and sent in for typesetting, it is expected to be in its final form.

OPEN ACCESS

LWW's hybrid open access option is offered to authors whose articles have been accepted for publication. With this choice, articles are made freely available online immediately upon publication. Authors may take advantage of the open access option at the point of acceptance to ensure that this choice has no influence on the peer review and acceptance process. These articles are subject to the journal's standard peer-review process and will be accepted or rejected based on their own merit.

Authors of accepted peer-reviewed articles have the choice to pay a fee to allow perpetual unrestricted online access to their published article to readers globally, immediately upon publication. The article processing charge for The *Journal of Strength & Conditioning Research* is $3,000. The article processing charge for authors funded by the Research Councils UK (RCUK) is $3,800. The publication fee is charged on acceptance of the article and should be paid within 30 days by credit card by the author, funding agency or institution. Payment must be received in full for the article to be published open access. Any additional standard publication charges, such as for color images, will also apply.

- ***Authors retain copyright***
  Authors retain their copyright for all articles they opt to publish open access. Authors grant LWW a license to publish the article and identify itself as the original publisher.

- ***Creative Commons license***
  Articles opting for open access will be freely available to read, download and share from the time of publication. Articles are published under the terms of the Creative Commons License Attribution-NonCommerical No Derivative 3.0 which allows readers to disseminate and reuse the article, as well as share and reuse of the scientific material. It does not permit commercial exploitation or the creation of derivative works without specific permission. To view a copy of this license visit: http://creativecommons.org/licenses/by-nc-nd/3.0.

- ***Compliance with NIH, RCUK, Wellcome Trust and other research funding agency accessibility requirements***
  A number of research funding agencies now require or request authors to submit the post-print (the article after peer review and acceptance but not the final published article) to a repository that is accessible online by all without charge. As a service to our authors, LWW identifies to the National Library of Medicine (NLM) articles that require deposit and transmits the post-print of an article based on research funded in whole or in part by the National Institutes of Health, Howard Hughes Medical Institute, or other funding agencies to PubMed Central. The revised Copyright Transfer Agreement provides the mechanism. LWW ensures that authors can fully comply with the public access requirements of major funding bodies worldwide. Additionally, all authors who choose the open access option will have their final published article deposited into PubMed Central.

  RCUK and Wellcome funded authors can choose to publish their paper as open access with the payment of an article process charge (gold route), or opt for their accepted manuscript to be deposited (green route) into PMC with an embargo.

  With both the gold and green open access options, the author will continue to sign the Copyright Transfer Agreement (CTA) as it provides the mechanism for LWW to ensure that the author is fully compliant with the requirements. After signature of the CTA, the author will then sign a License to Publish where they will then own the copyright. Those authors who wish to publish their article via the gold route will be able to publish under the terms of the Attribution 3.0 (CCBY) License. To view of a copy of this license visit: http://creativecommons.org/licenses/by/2.0/. Those authors who wish to publish their article via the green route will be able to publish under the rights of the Attribution Non-commercial 3.0 (CCBY NC) license (http://creativecommons.org/licenses/by-nc/2.0/).

  It is the responsibility of the author to inform the Editorial Office and/or LWW that they have RCUK funding. LWW will not be held responsible for retroactive deposits to PMC if the author has not completed the proper forms.

FAQ for open access

http://links.lww.com/LWW-ES/A48

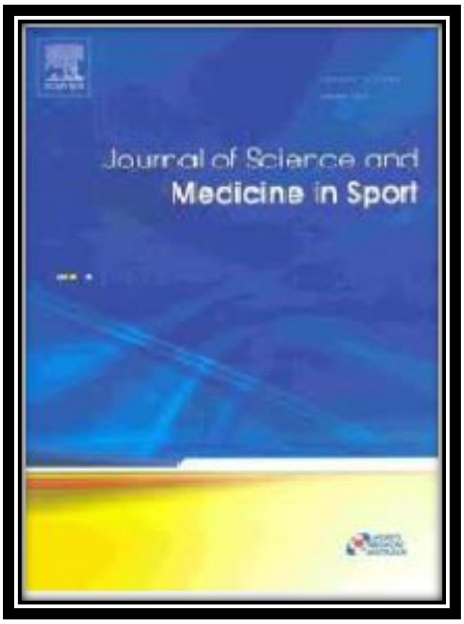
TERMINOLOGY AND UNITS OF MEASUREMENT

Per the JSCR Editorial Board and to promote consistency and clarity of communication among all scientific journals authors should use standard terms generally acceptable to the field of exercise science and sports science. Along with the American College of Sports Medicine's Medicine and Science in Sport and Exercise, the JSCR Editorial Board endorses the use of the following terms and units.

The units of measurement shall be Syste`me International d'Unite´ s (SI). Permitted exceptions to SI are heart rate—beats per min; blood pressure—mm Hg; gas pressure—mm Hg. Authors should refer to the British Medical Journal (1:1334 – 1336, 1978) and the Annals of Internal Medicine (106: 114 – 129, 1987) for the proper method to express other units or abbreviations. When expressing units, please locate the multiplication symbol midway between lines to avoid confusion with periods; e.g., mL_min-1_kg-1.
The basic and derived units most commonly used in reporting research in this Journal include the following: mass—gram (g) or kilogram (kg); force—newton (N); distance—meter (m), kilometer (km); temperature—degree Celsius (_C); energy, heat, work—joule (J) or kilojoule (kJ); power—watt (W); torque—newton-meter (N_m); frequency— hertz (Hz); pressure—pascal (Pa); time—second (s), minute (min), hour (h); volume—liter (L), milliliter (mL); and amount of a particular substance—mole (mol), millimole (mmol).

Selected conversion factors:
_ 1 N = 0.102 kg (force);
_ 1 J = 1 N_m = 0.000239 kcal = 0.102 kg_m;
_ 1 kJ = 1000 N_m = 0.239 kcal = 102 kg_m;
_ 1 W = 1 J_s-1 = 6.118 kg_m_min-1.

When using nomenclature for muscle fiber types please use the following terms. Muscle fiber types can be identified using histochemical or gel electrophoresis methods of classification. Histochemical staining of the ATPases is used to separate fibers into type I (slow twitch), type IIa (fast twitch) and type IIb (fast twitch) forms.Thework of Smerdu et. al (AJP 267:C1723, 1994) indicates that type IIb fibers contain type IIxmyosin heavy chain (gel electrophoresis fiber typing). For the sake of continuity and to decrease confusion on this point it is recommended that authors use IIx to designate what use to be called IIb fibers. Smerdu, V, Karsch-Mizrachi, I, Campione, M, Leinwand, L, and Schiaffino, S. Type IIx myosin heavy chain transcripts are expressed in type IIb fibers of human skeletal muscle. Am J Physiol 267 (6 Pt 1): C1723–1728, 1994.



Contributors are invited to submit their manuscripts in English to the Editor for critical peer review. The *Journal of Science and Medicine in Sport* considers for publication manuscripts in the categories of:
- Original Research
- Review Article

The manuscripts must be in one of the following sub-disciplines relating generally to the broad sports medicine and sports science fields: sports medicine, sports injury (including injury epidemiology and injury prevention), physiotherapy, podiatry, physical activity and health, sports science, biomechanics, exercise physiology, motor control and learning, sport and exercise psychology, sports nutrition, public health (as relevant to sport and exercise), and rehabilitation and injury management. Manuscripts with an interdisciplinary perspective with specific applications to sport and exercise and its interaction with health will also be considered.

Only studies involving **human subjects** will be considered.

Authors must declare that manuscripts submitted to the Journal have not been published elsewhere or are not being considered for publication elsewhere and that the research reported will not be submitted for publication elsewhere until a final decision has been made as to its acceptability by the Journal.

PLEASE NOTE: papers which do not meet the criteria below will be rejected immediately:
- Ensure that English is of good standard
- Ensure Ethics Committee details are as complete as possible
- Ensure all headings and subheadings conform to the Guide for Authors
- References, both in-text and reference list, must be formatted according to the Guide for Authors
- Provide the Figure Legends as part of the text file, at the end of the manuscript
- Include Acknowledgements (this is mandatory)

The review process will consist of reviews by at least two independent reviewers. Contributors must suggest the names and full contact details of 3 possible reviewers. The reviewers must not be from the same institutions as the authors, and one must be from a country different to any of the authors. The Editor may, at his or her discretion, choose no more than one of those suggested. The reviewers will be blinded to the authorship of the manuscript. The Editor will make a final decision about the manuscript, based on consideration of the reviewers' comments.

The journal receives an ever-increasing number of submissions and unfortunately can only publish a small proportion of manuscripts. The journal's Editorial Board does not enter into negotiations once a decision on a manuscript has been made. The Editor's decision is final.

Papers accepted for publication become the copyright of Sports Medicine Australia. Authors will be asked to sign a transfer of copyright form, on receipt of the accepted manuscript by Elsevier. This enables the publisher to administer copyright on behalf of the authors and the society, while allowing the continued use of the material by the author for scholarly communication.

PREPARATION OF MANUSCRIPTS

- Microsoft Word is the preferred software program. Use Arial or Times New Roman font, size eleven (11) point.
- Manuscript is double-spaced throughout (including title page, abstract, text, references, tables, and legends).
- Margins are 1 inch or 2.5 cm all around
- Include **page and line numbers** for the convenience of the peer reviewers.
- Number the pages consecutively, beginning with the title page as page 1 and ending with the Figure legend page.
- All headings (including the Title) should be in sentence-case only, not in capital letters.
- Sub-headings are generally not accepted. Incorporate into the text if required.
- Footnotes are not acceptable.
- Keep the use of tables, figures and graphs to a minimum.
- See notes on Tables, Figures, Formulae and Scientific Terminology at the end.

WORD COUNT LIMITS

Original Research papers

- 3000 word count limit (excluding title, abstract, tables/figures, figure legends, Acknowledgements, and References)
- Maximum number (combined) of tables and figures is 3
- Long tables should only be included as supplementary material and will be made available on-line only
- Maximum number of references is 30
- A **structured abstract** of less than 250 words (not included in 3000 word count) should be included with the following headings: Objectives, Design, Method, Results, and Conclusions

Review articles

- 4000 word count limit (excluding title, abstract, tables/figures, figure legends, Acknowledgements, and References)
- Maximum number (combined) of tables and figures is 3
- Long tables should only be included as supplemental files and will be available online only
- Maximum number of references is 60
- A **structured abstract** of less than 250 words (not included in 4000 word count) should be included sticking as closely as possible to the following headings: Objectives, Design, Method, Results, and Conclusions

SUBMISSION OF MANUSCRIPTS

All manuscripts, correspondence and editorial material for publication should be submitted online via the Elsevier Editorial System at http://www.ees.elsevier.com/jsams.

Authors simply need to "create a new account" (i.e., register) by following the instructions at the website, and using their own e-mail address and selected password. Authors can then submit manuscripts containing text, tables, and images (figures) online. The entire peer-review process will be managed electronically to ensure timely review and publication. Authors can expect an initial decision on their submission within 8 weeks.

Following registration, enter the "Author area" and follow the instructions for submitting a manuscript, including the structured Abstract, suggested reviewers, Cover letter, Tables, Figures, and any supplementary material.

If you wish to publish colour figures and agree to pay the "colour charge", tick the appropriate box. Colour illustrations incur a colour charge of 312 US dollars for the first page and 208 US dollars for every additional page containing colour. Figures can be published in colour at no extra charge for the online version. If you wish to have figures in colour online and black and white figures printed, please submit both versions.

The entire peer-review process will be managed electronically to ensure timely review and publication. Authors can expect an initial decision on their submission within 6 weeks.

Note: the online manuscript submission program requires separate entries of some information that also appears in the manuscript. These separate entries are needed to manage processing and review of your manuscript and correspondence.

Regulatory requirements

- *Research protocol*: Authors must state that the protocol has been approved by the appropriate ethics committee. Name the committee.
- *Human investigation*: The Ethical Guidelines followed by the investigators must be included in the Methods section of the manuscript.

STRUCTURE OF THE MANUSCRIPT (in order):

1. Cover Letter - Every submission, regardless of category must include a letter stating:
- the category of article: Original Research or Review article
- the *sub-discipline*: sports medicine, sports injury (including injury epidemiology and injury prevention), physiotherapy, podiatry, physical activity and health, sports science, biomechanics, exercise physiology, motor control and learning, sport and exercise psychology, sports nutrition, public health (as relevant to sport and exercise), rehabilitation and injury management, and others having an interdisciplinary perspective with specific applications to sport and exercise and its interaction with health.
- Sources of outside support for research (including funding, equipment and drugs) must be named.
- Financial support for the project must be acknowledged, or "no external financial support" declared.
- The role of the funding organisation, if any, in the collection of data, their analysis and interpretation, and in the right to approve or disapprove publication of the finished manuscript must be described in the Methods section of the text.
- When the proposed publication concerns any commercial product, either directly or indirectly, the author must include a statement (1) indicating that he or she has no financial or other interest in the product or distributor of the product or (2) explaining the nature of any relation between himself or herself and the manufacturer or distributor of the product.
- Other kinds of associations, such as consultancies, stock ownership, or other equity interests or patent-licensing arrangements, also must be disclosed. Note: If, in the Editor's judgment, the information disclosed represents a potential conflict of interest, it may be made available to reviewers and may be published at the Editor's discretion; authors will be informed of the decision before publication.
- The *Ethical Guidelines* that have been followed must be stated clearly. Provide the Ethics Committee name and approval number obtained for Human investigation.
- *Authors must declare* that manuscripts submitted to the Journal have not been published elsewhere or are not being considered for publication elsewhere and that the research reported will not be submitted for publication elsewhere until a final decision has been made as to its acceptability by the Journal.

Permission from the publisher (copyright holder) must be submitted to the Editorial Office for the reproduction of any previously published table(s), illustration(s) or photograph(s) in both print and electronic media or from any unmasked participants appearing in photographs.

2. Title Page (first page) should contain:
a. *Title*. Short and informative
b. *Authors*. List all authors by first name, all initials and family name
c. *Institution and affiliations*. List the name and full address of all institutions where the study described was carried out. List departmental affiliations of each author affiliated with that institution after each institutional address. Connect authors to departments using alphabetical superscripts.
d. *Corresponding author*. Provide the name and e-mail address of the author to whom communications, proofs and requests for reprints should be sent.
e. *Word count* (excluding abstract and references), the Abstract word count, the number of Tables, the number of Figures.

3. Manuscript (excluding all author details) should contain: (in order)

a. *Abstract* - must be structured using the following sub-headings: Objectives, Design, Methods, Results, and Conclusions. Avoid abbreviations and acronyms.

b. *Keywords* - provide up to 6 keywords, with at least 4 selected via the Index Medicus Medical Subject Headings (MeSH) browser list: http://www.nlm.nih.gov/mesh/authors.html. These keywords should not reproduce words used in the paper title.

c. Main body of the text.

For Original Research papers, text should be organised as follows:

i. *Introduction* - describing the (purpose of the study with a brief review of background

ii. *Methods* - described in detail. Include details of the Ethics Committee approval obtained for Human investigation, and the ethical guidelines followed by the investigators. This section is not called Materials and Methods, and should not include subheadings. Do not use the term "subjects" - use terms such as "participants", "patients" or "athletes", etc.

iii. *Results* - concisely reported in tables and figures, with brief text descriptions. Do not include subheadings. Use small, non-italicized letter p for p-values with a leading zero, e.g. 0.05; Measurements and weights should be given in standard metric units. Do not replicate material that is in the tables or figures in the text.

iv. *Discussion* - concise interpretation of results. Cite references, illustrations and tables in numeric order by order of mention in the text. Do not include subheadings.

v. *Conclusion*

vi. *Practical Implications* - 3 to 5 dot (bulleted) points summarising the practical findings derived from the study to the real-world setting of sport and exercise - that can be understood by a lay audience. Avoid overly scientific terms and abbreviations. Dot points should not include recommendations for further research.

vii. *Acknowledgments* - this section is compulsory. Grants, financial support and technical or other assistance are acknowledged at the end of the text before the references. All financial support for the project must be acknowledged. If there has been no financial assistance with the project, this must be clearly stated.

viii. *References* - authors are responsible for the accuracy of references.

ix. *Tables* - may be submitted at the end of the text file, on separate pages, one to each page.

x. *Figure Legends* - must be submitted as part of the text file and not as illustrations.

4. Figures - must be submitted as one or more separate files that may contain one or more images.

5. Supplementary material (if any) - tables or figures to be viewed online only

REFERENCES

- References should be **numbered consecutively** in un-bracketed superscripts where they occur in the text, tables, etc, and listed numerically (e.g. "1", "2") at the end of the paper under the heading "References".

- For Original Research papers, **no more than three references** should be used to support a specific point in the text.

- All authors should be listed where there are three or fewer. Where there are more than three, the reference should be to the first three authors followed by the expression "et al".

- Book and journal *titles* should be in *italics*.

- Conference and other abstracts should not be used as references. Material referred to by the phrase "personal communication" or "submitted for publication" are not considered full references and should only be placed in parentheses at the appropriate place in the text (e.g., (Hessel 1997 personal communication). References to articles submitted but not yet accepted are not encouraged but, if necessary, should only be referred to in the text as "unpublished data".

- Footnotes are unacceptable.

- **Book references:**
Last name and initials of author, chapter title, chapter number, italicised title of book, edition (if applicable), editor, translator (if applicable), place of publication, publisher, year of publication.

Example:
Wilk KE, Reinold MM, Andrews JR. Interval sport programs for the shoulder, Chapter 58, in *The Athlete's Shoulder*, 2nd ed., Philadelphia, Churchill Livingstone, 2009

- **Journal references:**
Last name and initials of principal author followed by last name(s) and initials of co-author(s), title of article (with first

word only starting in capitals), abbreviated and italicised title of journal, year, volume (with issue number in parenthesis if applicable), inclusive pages.

For guidance on abbreviations of journal titles, see Index Medicus at www.nlm.nih.gov/tsd/serials/lji.html.

Example:
Hanna CM, Fulcher ML, Elley CR et al. Normative values of hip strength in adult male association football players assessed by handheld dynamometry. *J Sci Med Sport* 2010; 13(3):299-303.

- **Internet references** should be as follows:
Health Care Financing Administration. 1996 statistics at a glance. Available at: http://www.hcfa.gov/stats/stathili.htm. Accessed 2 December 1996.

- **Articles in Press** are cited using a DOI: http://www.doi.org. The correct format for citing a DOI is as follows: doi:10.1016/j.jsams.2009.10.104.

TABLES

- Tables should be part of the text file, placed on separate sheets (one to each page) after the References section. Do not use vertical lines.
- Each table should be numbered (Arabic) and have a title above. Legends and explanatory notes should be placed below the table.
- Abbreviations used in the table follow the legend in alphabetic order.
- Lower case letter superscripts beginning with "a" and following in alphabetic order are used for notations of within-group and between-group statistical probabilities.
- Tables should be self-explanatory, and the data should not be duplicated in the text or illustrations.

FIGURE LEGENDS

- Figure legends should be numbered (Arabic) and double-spaced in order of appearance, beginning on a separate page.
- Identify (in alphabetic order) all abbreviations appearing in the illustrations at the end of each legend.
- All abbreviations used on a figure and in its legend should be defined in the legend.
- Cite the source of previously published (print or electronic) material in the legend.
- Figure legends must be submitted as part of the text file and not as illustrations.

FIGURES AND ILLUSTRATIONS

- Images or figures are submitted online as one or more separate files that may contain one or more images.
- Within each file, use the figure number (e.g., Figure 1A) as the image filename.
- The system accepts image files formatted in TIF and EPS. PowerPoint (.ppt) files are accepted, but you must use a separate PowerPoint image file for each PowerPoint figure.
- Symbols, letters, numbers and contrasting fills must be distinct, easily distinguished and clearly legible when the illustration is reduced in size.
- Black, white and widely crosshatched bars are preferable; do not use stippling, gray fill or thin lines.
- Written permission from unmasked patients appearing in photographs must be obtained by the authors and must be surface mailed or faxed to the editorial office once the manuscript is submitted online.

FORMULAE, Equations and Statistical Notations

- Structural formulae, flow-diagrams and complex mathematical expressions are expensive to print and should be kept to a minimum.
- Present simple formulae in the line of normal text, where possible. Use a slash (/) for simple fractions rather than a built up fraction. Do not use italics for variables.
- In statistical analyses, 95% confidence intervals should be used, where appropriate. Experimental design should be concisely described and results summarised by reporting means, standard deviations (SD) or standard errors (SE) and the number of observations. Statistical tests and associated confidence intervals for differences or p-values should also be reported when comparisons are made. Only use normal text for statistical terms: do not use bold, italics or underlined text.

SCIENTIFIC TERMINOLOGY

- To enable consistency, authors should generally follow the technical guidelines of Medicine and Science in Sports and Exercise, unless otherwise stipulated in these Instructions.
- Following are some examples of the Journal style in the most basic cases and some general SI unit guidelines.

- Mass: 10 g, 2 kg
- Temperature: 20 o C
- Distance: 10 cm, 4 m, 20 km
- Time: 10 s, 20 min, 2 hr, 5 wk, 1 y
- Power: 10 W
- Energy: 400 J, 10 kJ.

- The centigrade scale (C) and the metric units (SI) must be used, except in the case of heart rate (beats per min: bpm), blood pressure (mmHg) and gas pressure (mmHg).
- When opening a sentence, numbers should be expressed in words, e.g.: Forty-seven patients were contacted by phone.
- The 24-hour clock should be useD