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**The use of cold water immersion in elite rugby union athletes**

A thesis  
submitted in fulfilment  
of the requirements for the degree  
of  
**Doctor of Philosophy**  
**Health, Sport and Human Performance**  
at  
**The University of Waikato**  
by  
**FRANCISCO TAVARES**



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## **Abstract**

Athletes are exposed to training stimuli that lead to temporary states of impaired performance (i.e. fatigue). Adaptation from training will occur in response to the balance between the training load and recovery. Frequently, athletes are exposed to high density training phases, leaving only limited timeframes for recovery between training sessions and/or competition. Therefore, in order to enhance recovery, different modalities are commonly implemented. Given its efficacy in the research literature, cold modalities, in particular cold-water immersion (CWI), is a frequently employed and studied recovery modality. While the effects of CWI on enhancing recovery in the acute timeframe are widely investigated, recent research has demonstrated that chronic exposure to CWI may decrease anabolic pathway signaling, therefore reducing muscle growth adaptations. However, there is currently a lack of well-designed studies on chronic use of CWI in athletic populations exposed to high training loads and frequencies.

The purpose of this series of studies was to compare the acute and chronic effects of CWI in well-trained and elite team sport athletes. This thesis comprises of seven studies that aim to add knowledge to the current scientific literature investigating the effects of CWI and provide guidelines to practitioners working with elite athletes.

**Study One** is a narrative literature review that provides a background to the current scientific knowledge of the recovery modalities implemented in rugby. In this review, CWI was observed to be the most frequently used recovery modality in rugby. In addition, limitations are discussed relating to the methodology of previous studies that

have investigated the effects of chronic exposure to CWI. The rationale for the acute benefits of CWI as well as the possible harmful effects of chronic CWI implementation are highlighted.

**Study Two** is a cross-sectional study comparing the usage and perceived effectiveness of different recovery modalities in elite and amateur rugby players. Fifty-eight elite (n = 32) and amateur (n = 26) rugby athletes were surveyed on the usage and perception of 15 different recovery modalities. The elite group perceived active recovery, massage, pool recovery, additional sleep, and stretching to be significantly more effective in comparison to the amateur group. Moreover, the elite group implemented a greater number of recovery modalities and also had a greater frequency of use per week in comparison to the amateur group. The top five recovery modalities in terms of perceived effectiveness were: stretching, cold water immersion, active recovery, additional sleep, and pool recovery in the elite group; and cold water immersion, stretching, contrast baths, additional sleep, and massage in the amateur group.

In **Studies Three and Four**, acute physiological and perceptual responses were obtained during a training period in elite rugby athletes. In **Study Three**, a muscle soreness questionnaire was implemented during a nine-day in-season period with 19 elite rugby athletes, to understand if training affected soreness to the same extent at different muscle sites. The muscle soreness questionnaire consisted of soreness ratings from nine different body parts (five lower body and four upper body), from left and right sides. The major finding of this study was that while muscle soreness from the different lower body sites increased on the mornings following training days and the match, the muscle soreness from the upper body sites only increased on the days

following a match. Monitoring soreness from different muscle sites, particularly lower body, may provide important information for practitioners. In **Study Four**, 16 elite rugby athletes were monitored during a non-competitive, in-season training week. The same muscle soreness questionnaire (from **Study Three**) in conjunction with a wellness questionnaire and a countermovement jump test (**Appendix C**) were used to monitor fatigue. The wellness questionnaire is commonly used to monitor fatigue and consisted of five questions (sleep quality, general muscle soreness, fatigue, stress, and mood). An effect of training load was observed on the different measures obtained, with this effect being more pronounced following two consecutive training days in comparison to a single training day. As muscle soreness was collected from different muscle sites (i.e. soreness questionnaire) and also from a single question of muscle soreness (i.e. wellness questionnaire), we were able to compare the different measures and conclude that monitoring soreness from different muscle sites may provide important information regarding fatigue, readiness to train, and prevention of injuries.

**Study Five** was designed to understand the efficacy of CWI in elite rugby athletes. Twenty-three athletes were randomly assigned to a control group (no CWI) or an experimental group (CWI four times per week following the last training session of the day). Acute (i.e. during the training week) and chronic (i.e. over the three-week pre-season phase) physiological and perceptual responses of the athletes were monitored. Overall, while the control group demonstrated an increased level of muscle soreness and decreased neuromuscular function (demonstrated by a decrease in the countermovement jump performance) throughout the duration of the study, the athletes exposed to CWI maintained neuromuscular performance and presented lower levels of

muscle soreness. Moreover, in the control group, athletes demonstrated an increase in interleukin-6 that was not observed in the CWI group. These findings demonstrate that CWI may provide some beneficial effect by reducing fatigue, soreness, and inflammation within the training week and during an intense three-week pre-season phase.

**Study Six**, was written to provide practical recommendations to practitioners on the implementation of cold and contrast water modalities. The nature of the cold water modalities was discussed as a more intense cold water modality protocol (e.g. increased immersion duration, decreased water temperature) may be more effective in re-establishing performance, but also may have an increased blunting effect on muscle growth in the chronic setting, based on the manipulated characteristics (i.e. water temperature, exposure time, type, immersion depth). Recommendations and examples were presented regarding the phase of the season, density of the schedule, and athletes' goals.

In summary, the series of studies in this thesis provide a deeper understanding on the effects of cold water immersion in team-sport athletes in general and rugby in particular. The findings of these studies demonstrate that while rugby training affects athlete performance and other markers associated with fatigue, CWI can be implemented as a strategy to accelerate recovery. These studies add to the current body of knowledge, demonstrating that when rugby athletes are exposed to a dense training week (i.e. four resistance training sessions, seven rugby field sessions, two speed sessions, and four extra-conditioning sessions per week), CWI may attenuate increases in muscle soreness and allow for maintenance of neuromuscular performance. Further

research should aim to investigate if the beneficial effects of CWI observed by us outweigh the potential harmful effects on protein synthesis and muscle growth adaptation from training.

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***He piko he taniwha, he piko he taniwha (around every bend there is a chief).***

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## List of Abbreviations

1-RM	One maximal repetition
Akt	Protein kinase B
ANOVA	Analysis of variance
AR	Active recovery
AST	Aspartate aminotransferase
AU	Arbitrary Units
Avg	Average
BM	Body mass
BSA	body surface area
C	Cortisol
C3	Complement component 3
CG	Compression garments
CI	Confidence intervals
CK	Creatine kinase
CMJ	Countermovement jump
CMJB	Countermovement jump to a box
Con	Conditioning session
CRP	C-reactive protein
CV	Coefficient of variance
CWI	Cold water immersion
CWT	Contrast water therapy
d	Cohen's effect sizes
DOMS	Delayed onset muscle soreness
EIMD	Exercise induced muscle damage
ELISA	Enzyme linked immunosorbent assay
EMS / NMEST	Electromyostimulation/Neuromuscular electrostimulation
ES	Effect size
FP	Force plate
GOT	Glutamate oxaloacetate transaminase
GPS	Global Positioning System
GPT	Glutamate pyruvate transaminase
h	Hours
HCO <sub>3</sub> <sup>-</sup>	Bicarbonate
HML	High metabolic load distance
HR	Heart rate
HT	Hypertrophy session
Hz	Hertz

I/N	Insufficient number
ICC	Intraclass correlation
Ig	Immunoglobulin
IL-6	Interleukin-6
IRB	International rugby board
IRTL1	Intermittent recovery test level 1
J	Jumping performance
kg	Kilograms
La <sup>-</sup>	Lactate
LBRT	Lower body resistance training
LDH	Lactate dehydrogenase
m	Meters
Max	Maximal
min	Minutes
mL	Millilitre
mTOR	Mammalian target of rapamycin
MVA	Maximal voluntary activation
MVC	Maximal voluntary contraction
N	Newtons
n.a.	Not available
N/E	Not experimented
NSAID	Nonsteroidal anti-inflammatory drugs
OF	On-field session
OR	Overreaching
OT	Overtraining
P	Power session
PAS	Passive recovery
PF	Peak force
pg	Picogram
PGC-1 $\alpha$	Transcriptional coactivator peroxisome proliferators– activator receptor gamma coactivator-1 alpha
pmol	Picomole
PPDC	Peristaltic pulse dynamic compression
PS	Pool session
Q	Wellness questionnaire
QWS	Questionnaires of soreness and wellness
r	Pearson product-moment correlation
RPE	Rate of perceived exertion
S	Soreness questionnaire
Sal	Saliva sample

SD	Standard deviation
sEMG	Surface electromyography
sRPE	Session rate of perceived exertion
SS	Strength session
T	Testosterone
T <sub>c</sub>	Core temperature
TE	Typical error
TEE	Typical error of estimate
T <sub>sk</sub>	Skin temperature
TT	Technical-tactical session
U	Units
U20	Under twenty
UBRT	Upper body resistance training
UK	United Kingdom
μL	Microliters
USA	United States of America
USB	Universal serial bus
VL	Vastus lateralis
VM	Vastus medialis
WB	Whole body resistance training
WBC	Whole body cryotherapy

# **CHAPTER ONE**

## **Thesis Overview**

Rugby union is a team sport played in several countries worldwide. Like most team sports, rugby is an intermittent sport, with bouts of high intensity efforts being interspersed with low intensity activities or rest. High intensity activities in rugby can be divided as locomotive (high speed runs, sprints, acceleration) and collision-based activities (tackling, scrums, rucks and mauls) [1–3].

In order to prepare for the rugby match requirements, athletes are exposed to different training stimulus in the field and weights room during the training week. At the elite level, it is frequently for rugby athletes to train two or more times during the day over two or more consecutive days [4–6]. Therefore, the collision-based and high-intensity intermittent nature of rugby practice and competition, together with the strength and power training characteristics in the weights room, lead to notable muscle damage and fatigue post-training and competition [7–9].

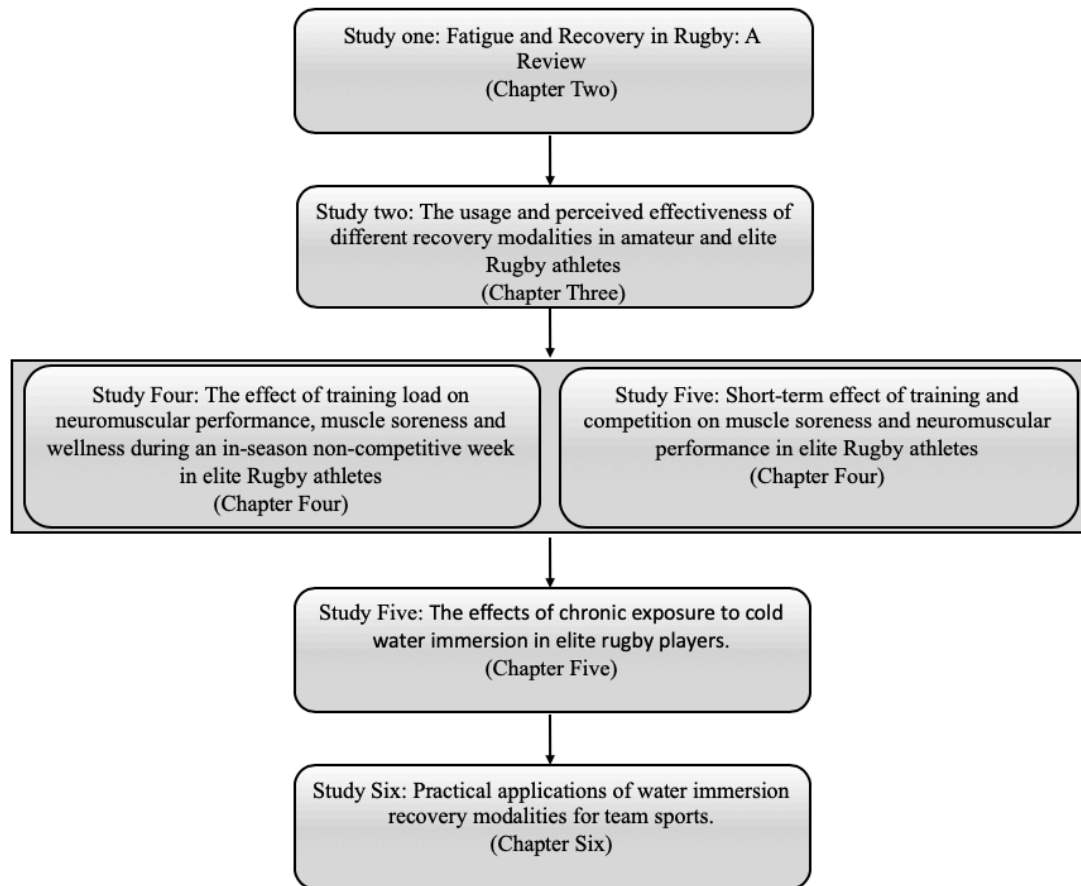
The high training frequency that occurs during the training week in elite athletes often results in an insufficient time to recover. An imbalance between training and recovery can lead to acute decreases in performance and to an excessive level of accumulated fatigue over the training week that can result in undesirable chronic fatigue over a training phase [10–12].

In order to speed-up recovery to allow athletes to perform at greater intensities and reduce the risk of maladaptation, practitioners and sport scientists frequently implement different recovery modalities. Cold modalities, including cold water immersion, have been demonstrated to be common methods to enhance recovery from rugby training and competition. This thesis aims to add further knowledge on the acute

and chronic effects of cold water immersion used to enhance recovery in highly-trained rugby athletes.

Seven studies including a review of the literature and a manuscript providing applied recommendations to practitioners are either published or in press in peer-reviewed journals. Three additional papers related to the topic of this thesis have also been published in peer-reviewed journals and are included in the appendices of the thesis.

**Chapter Two** is a narrative literature review that outlines the current scientific knowledge of recovery modalities implemented in rugby. **Chapter Three** aimed to understand the usage and perceived effectiveness of 15 different recovery modalities in elite and amateur rugby. **Chapter Four** aimed to demonstrate the acute physiological (neuromuscular) and perceptual (soreness and wellbeing) responses during a short training period (i.e. seven to nine days) in elite rugby athletes. **Chapter Five** was designed to understand the acute and chronic effects of CWI of elite rugby athletes over three weeks. **Chapter Six** provides practical recommendations for practitioners on the implementation of cold and contrast water modalities.



**Figure 1.** Schema of the thesis.

## **Chapter Organisation**

This thesis comprises of seven chapters. Given that each study is presented in a format for publication in different peer-reviewed journals, each study consists of its own sections (e.g. abstract, introduction, methodology, results and discussion). Due to the structure of the thesis, with each chapter submitted as a standalone piece of research work for publication, there is a degree of repetition throughout the thesis. There is a single reference list of citations included at the end of the thesis.

## **Publications Arising from this Thesis**

The following publications directly resulting from the work in this thesis are either published or accepted for publication (In Press):

1. **Tavares, F.**, Smith, T. B., Driller, M. (2017). Fatigue and recovery in rugby: A review. *Sports Medicine*, 47(8), 1515-1530.
2. **Tavares, F.**, Healey, P., Smith, T. B., Driller, M. (2017). The usage and perceived effectiveness of different recovery modalities in amateur and elite rugby athletes. *Performance Enhancement & Health*, 5(4), 142-146.
3. **Tavares F.**, Healey P., Smith TB., Driller, M. (2018). Short-term effect of training and competition on muscle soreness and neuromuscular performance in elite rugby athletes. *Journal of Australian Strength and Conditioning*, 26(1), 11-17.
4. **Tavares F.**, Healey P., Smith TB., Driller, M. (2018). The effect of training load on neuromuscular performance, muscle soreness and wellness during an in-season non-competitive week in elite rugby athletes. *The Journal of Sports Medicine and Physical Fitness*. Epub ahead of print
5. **Tavares, F.**, Beaven, M., Teles, J., Baker, D., Healey, P., Smith, T. B., Driller, M. (2018). The effects of chronic cold water immersion in elite rugby players. *International Journal of Sports Physiology and Performance*. Epub ahead of print
6. **Tavares, F.**, Walker, O., Healey, P., Smith, T. B., Driller, M. (2018). Practical applications of water immersion recovery modalities for team sports. *Strength and Conditioning Journal*, 40(4):48-60.

## Appendices

1. **Tavares, F.**, Simões, M., Matos, B., Smith, T B., Driller, M. (2017). Wellness, muscle soreness and neuromuscular performance during a training week in volleyball athletes. *The Journal of Sports Medicine and Physical Fitness*. Epub ahead of print
2. Matos, F., Neves, E. B., Rosa, C., Reis, V. M., Saavedra, F., Silva, S., **Tavares, F.**, Vilaça-Alves, J. (2018). Effect of cold-water immersion on elbow flexors muscle thickness after resistance training. *The Journal of Strength and Conditioning Research*, 32(3), 756-763.
3. **Tavares, F.**, McMaster, T., Healey, P., Smith, T. B., Driller, M. (2018). A novel method to reduce the impact of countermovement jump monitoring in professional rugby athletes. *Journal of Athletic Enhancement*, 7(1).

## Conference Presentations from this Thesis

1. **Tavares, F.**, Healey, P., Smith, T. B., Driller, M. Effect of training load on acute fatigue and wellness during an in-season non-competitive week in elite rugby athletes. *Sport and Exercise Science New Zealand conference*. 2016. Cambridge, New Zealand.
2. **Tavares, F.**, Healey, P., Smith, T, B., Driller, M. The usage and perceived effectiveness of different recovery modalities in amateur and elite rugby athletes. *Sport and Exercise Science New Zealand conference*. 2016. Cambridge, New Zealand.
3. **Tavares, F.**, Beaven, M., Silvestre, R., Teles, J., Baker, D., Healey, P., Smith, T., Driller, M. The effect of cold water immersion during a pre-season week in elite rugby athletes. *6th NSCA International Conference*. 2018. Madrid, Spain.



## **CHAPTER TWO**

### **Fatigue and recovery in rugby: A review.**

**Tavares F, Smith TB, Driller M.** Fatigue and recovery in rugby: A Review. *Sports Medicine* 2017;47(8):1515–1530.

Rugby has been demonstrated to elicit both acute and chronic fatigue. In order to speed-up recovery, numerous recovery modalities are frequently implemented by sport scientists and practitioners. However, a current review of scientific literature on the effects that different modalities have on recovery in rugby is lacking. Therefore, in this chapter we reviewed the published scientific literature investigating the effects of different recovery modalities in rugby.

## **Abstract**

The physical demands and combative nature of rugby lead to notable levels of muscle damage. In professional rugby, athletes only have a limited timeframe to recover following training sessions and competition. Through the implementation of recovery strategies, sport scientists, practitioners and coaches have sought to reduce the effect of fatigue and allow athletes to recover faster. Although some studies demonstrate that recovery strategies are extensively used by rugby athletes, the research remains equivocal concerning the efficacy of recovery strategies in rugby. Moreover, given the role of inflammation arising from muscle damage in the mediation of protein synthesis mechanisms, some considerations have been raised on the long-term effect of using certain recovery modalities that diminish inflammation. While some studies aimed to understand the effects of recovery modalities during the acute recovery phase (< 48 hours post-match), others investigated the effect of recovery modalities during a more prolonged timeframe (i.e. during a training week). Regarding the acute effectiveness of different recovery modalities, cold water immersion and contrast baths seem to provide a beneficial effect on creatine kinase clearance, neuromuscular performance and delayed onset of muscle soreness. There is support in the literature concerning the effect of compression garments on enhancing recovery from delayed onset of muscle soreness, however conflicting findings were observed for restoration of neuromuscular function with the use of this strategy. Using a short-duration active recovery protocol seems to yield little benefit to recovery from rugby training or competition. Given that cold modalities may potentially affect muscle size adaptations from training, their inclusion should be treated with caution and perhaps restricted to certain periods where

athlete readiness is more important than increases in muscle-size.

**Key Points:**

Acutely (< 48 hours post-match), cold modalities seem to have a beneficial effect on creatine kinase (CK) clearance, neuromuscular performance and delayed onset of muscle soreness (DOMS).

Compression garments provide enhanced recovery from DOMS, and in combination with electromyostimulation, may provide a beneficial effect on CK clearance and perceptual wellbeing during the training week.

A typical short-duration (i.e. 7 minutes) active recovery protocol is unlikely to provide additional benefits for recovery.

The usage of recovery modalities that may affect hypertrophy signalling pathways, therefore limiting adaptations in muscle size (i.e. cold modalities), should be treated with caution and perhaps restricted to certain periods.

## **Introduction**

Rugby (union and league) is a high-intensity team sport played worldwide [13,14]. Like most team sports, the effort in rugby is intermittent, with bouts of high intensity interspersed with low intensity activities or rest [1, 3,15,16]. High intensity actions are normally categorized as high speed runs, sprints, acceleration/decelerations, and collision-based activities like tackling, static holds, scrums, rucks and mauls [1, 3,15,16]. The physical demands of rugby union [1,17] and rugby league [16] have been recently reviewed elsewhere. The combative and high-intensity intermittent nature of rugby lead to notable muscle damage post-training and competition [18,19]. Given this, alterations in neuromuscular performance and reports of perceptual fatigue have been described for up to 48 hours [7,9] and four days post-match [8], respectively. Rugby training often occurs less than 48 hours post-match with athletes training for two or more consecutive days during a week [6], therefore, it is likely that the players' readiness (e.g. neuromuscular performance) is compromised [7–9]. The limited time to recovery can lead to an excessive level of accumulated fatigue over the week cycle that may lead to under-performance on match day, as observed during an intensified junior rugby competition period [10,11], and undesirable fatigue states over a training phase [12].

Through the implementation of recovery strategies, sports scientists and coaches have sought to reduce the deleterious effect of fatigue and allow athletes to recover faster [7, 9,20–24]. Moreover, a growing body of research has focused on the recovery modalities from training [25–27], and competition [9, 20,28,29]. In fact, ~93% of the intervention studies included in this review were published in the last decade (2006 –

2016) and ~64% of these in the last five years (2011 – 2016) (Table 1 and Table 2). Also, to the best of our knowledge, there are no reviews that have evaluated the literature relating to recovery modalities following rugby training and/or competition.

The primary purpose of this review is to summarise the scientific literature regarding recovery modalities in rugby union and league. The relevant literature for this review was obtained from a search within the MEDLINE/PubMed, SPORTDiscus, Web of Science and Cochrane databases. Included terms for the searches were: ‘recovery strategies rugby’, ‘recovery modalities rugby’, ‘recovery rugby’ ‘cryotherapy rugby’, ‘cold water immersion rugby’, ‘contrast baths rugby’, ‘active recovery rugby’, ‘compression garment rugby’, ‘pool recovery rugby’, ‘electromyostimulation rugby’, ‘peristaltic pulse dynamic compression rugby’, ‘massage rugby’, ‘passive recovery rugby’. Relevant literature was also obtained from related articles that arose from the references listed in the articles acquired from the database searches. The inclusion criteria were limited to the English language and studies published prior to August 2016. Fourteen studies were included for analysis. From these 14 articles, five included elite rugby athletes, four well-trained rugby athletes and five were club or collegiate-level rugby athletes. Seven articles utilized cold water immersion (CWI), five utilized contrast water therapy (CWT), six utilized compression garments (CG), one utilized cryotherapy, four utilized active recovery (AR) and one utilized electromyostimulation (EMS). Moreover, two articles utilized a combination of two or more recovery modalities.

## **Fatigue from rugby**

Chronic adaptations to exercise generally occur based on the training load/stimulus and the recovery time between training sessions. Training promotes a disturbance to homeostasis that leads to a physiological response and a temporary impairment to an athlete's performance [7, 9–11, 24,25,30,31]. As it happens during exercise, also during recovery from exercise, physiological responses occur [32]. The recovery timeframe can be categorized into immediate (e.g. recovery between strength training repetitions), short-term (e.g. recovery between sprinting sets), and long term recovery (e.g. recovery between training sessions) [32]. The stress and fatigue imposed by a set of six maximal repetitions of weight training differs from the stress and fatigue arising from a 90-minute soccer match [33]. Nevertheless, in both cases, the capability to perform is temporarily reduced, returning to a baseline level in different timeframes [34]. For the purpose of this review, recovery will be defined as the biological occurrences between the end of one training stimulus and the beginning of the next [32].

Rugby athletes frequently train two or more times daily for two or more consecutive days [6, 8, 19,35]. The high density of the weekly schedule results in a limited time for recovery between training sessions, which is associated with a decrease in performance [7–9]. Moreover, an increase in training load that can be partly attributed to increases in training frequency can lead to a greater risk of injury [17]. Factors such as rest, sleep, nutrition and hydration, have been recognized as essential components in the recovery from training [32,36–39]. In a study designed to understand team athletes' perceptions of the importance of different recovery strategies, rugby union athletes (n = 317) ranked

socializing with friends, nutrition, hydration and sleep as amongst the six most important recovery modalities [38]. Nevertheless, given the density schedule of the training week, in addition to the essential components of recovery (e.g. rest, sleep, nutrition and hydration), athletes often seek to implement recovery modalities to further enhance or ‘speed-up’ recovery from exercise [38,40–42].

Rugby athletes are often exposed to high load / high velocity of contraction, either in the gym or on the field [6,43,44]. Neural adaptations are known to be dependent on the quality of the training session, with high power/velocity outputs being desirable for every repetition [45,46]. For this reason, enhanced recovery is essential for allowing athletes to perform maximally (i.e. high power outputs). Our laboratory surveyed a group of elite rugby athletes (n = 32) on the perception and usage of modalities to enhance recovery from exercise induced muscle damage (EIMD) in addition to adequate nutrition, hydration, sleep and rest. Analysis of the data suggested that athletes were using a median of seven different recovery strategies during the training week (ranging from 5 to 10) (Francisco Tavares, Phil Healey, Tiaki Brett Smith & Matthew Driller; unpublished observations). Moreover, data from anecdotal reports and questionnaire studies demonstrate that rugby athletes use a diversity of recovery strategies [42]. Therefore, a plethora of interventional research studies have investigated the efficacy of different recovery strategies [9,47], spanning different athletic abilities [7, 20, 24,48] and sports [7,48–50]. While previous articles have reviewed the effects of different recovery modalities in other team sports (e.g. soccer [39,51]), to the best of our knowledge, no study has reviewed the literature examining the efficacy of different recovery modalities in rugby.

In rugby, the impact from training and competition on fatigue is well reported in the scientific literature [7, 9–11, 24,25,30,31] and was recently reviewed elsewhere [52,53]. Muscle damage and the consequent inflammation from rugby play a primary role in the decreased capability to perform (i.e. fatigue state). The causes of EIMD from rugby can be largely attributed to the collisions and to the high frequency and intensity of eccentric contractions [18,19]. Moreover, the stress associated with the metabolic deficiencies resulting from a rugby match or training session is also likely to be associated with EIMD [54]. Collisions and tackles in rugby are known to have a large impact on muscle integrity [18,19,35]; therefore, a relationship can be found between the number and intensity of collisions and the level of muscle damage [18, 35,55,56]. Moreover, a relationship between the number and intensity of collisions and lower body neuromuscular performance (i.e. peak rate of force development and peak power during a countermovement jump) after a rugby match has also been observed [57]. Compared to other types of muscle contractions, eccentric contractions are known to play the greatest role in muscle damage. During eccentric contractions, cross-bridges are broken as a result of the high contraction forces associated with muscle lengthening [58], leading to a disruption of both the contractile proteins and other structural proteins in the muscle cell [59,60]. In team sports like rugby, eccentric actions such as changing direction, deceleration, landing from a jump or any other type of stretch shortening cycle activity occur frequently [52,53]. Thus, post training or competition, muscle damage is expected [61,62].

As described by Twist and Highton [53] muscle damage is characterized by a disruption of the contractile and structural proteins inducing an inflammatory response

and alterations in the excitation-contraction coupling mechanism. As a consequence of rugby competition the expected high muscle damage levels have been reported to reduce neuromuscular performance and increase both perceptual fatigue and perceptual muscle soreness for up to 48 hours post-match [7–9,35]. Moreover, biochemical and endocrine responses seem to return to baseline values 17 to 48 hours after a rugby match [19, 28,63]. However, more prolonged changes in markers of EIMD have also been reported post-match in the rugby literature [8, 18,19,64]. These changes include elevation of indirect markers of muscle damage (i.e. creatine kinase elevated up to 120 hours [18,19]), alterations in endocrine responses (i.e. testosterone to cortisol ratio elevated for up to four days [64]), decreases in neuromuscular function (i.e. countermovement performance impaired for up to four days [8]) and elevated perceived fatigue and muscle soreness (i.e. perceptual changes in wellbeing questionnaires up to four days [8]). Despite indications of EIMD, the rugby athletes in all the aforementioned studies maintained their normal training routines. While the specific training regimes were not reported in all of the above studies, professional rugby players typically perform two resistance training sessions and three to four skills/conditioning training sessions with one game in a typical in-season week [6, 8, 19,35]. Although training loads are adjusted in accordance with the number of days between rugby matches [8], the more prolonged fatigue reported is likely to be associated with a combination of the physiological stress from the match and the subsequent training sessions.

Direct measurement of muscle damage is possible through different imaging techniques [60,65–67], however, the use of such techniques is not always feasible in

normal training environments. Rather, indirect muscle damage indicators such as muscle proteins, enzymes and hormones are used to monitor muscle damage [18,19, 28,55,56]. As a consequence of intense exercise and/or muscle trauma, disturbances or disintegration of skeletal muscle structure are associated with leakage of various intracellular components and their subsequent elevated concentrations in the bloodstream [68].

Creatine kinase (CK) is the most common marker of muscle damage used in the rugby literature [7, 9,10, 18–20, 24, 29,30,69–71]. Nevertheless, CK demonstrates a large individual variability and a poor temporal relationship with muscle function recovery [35,72]. For example, in rugby, no relationship has been observed between the values of CK and muscle function measured by jump performance [35]. For this reason, some reservations to using CK as a monitoring tool in team-sports [73] and more specifically in rugby [52,53] have been raised. In addition, other blood and salivary markers of fatigue have been extensively used in rugby [18,19, 28,29,63,64]. Measurements of hormonal and enzymatic responses to training and competition may be useful to monitor fatigue. However, they are expensive, time-consuming and somewhat impractical to implement [53,73]. Also, the usefulness of some of these markers on a routine basis is still to be proven [73].

For these reasons, rugby coaches and sport scientists are advised to understand the limitations and take care when using blood and salivary markers of fatigue [53]. Nevertheless, monitoring fatigue is essential to understand the impact of training and competition, and to avoid undesirable training states (i.e. non-functional overreaching, overtraining) and injury [17, 52,53,73]. Usually one or more tests are implemented over

time to inform coaches about the readiness to perform, fatigue levels and general health status of an athlete [31,52,53]. In a recent review paper [53] and book chapter [52], Twist and Highton have systematically categorized and describe the different available tools to monitor fatigue in rugby (i.e. questionnaires and subjective assessments, blood and salivary markers, neuromuscular function and performance tests) in terms of their validity and applicability.

## **Recovery modalities in the rugby literature**

The effects of different recovery modalities have been investigated in respect to recovery from rugby matches [9, 20, 22, 27–29, 70,74], including simulated matches [22, 24,25,47], and from training [7, 20, 23, 25, 27, 29, 47,69]. Moreover, the effects of single recovery modalities [7, 20–25, 27, 47,69] or a combination of different recovery modalities [28,29], have been investigated. Cold modalities including cold baths [7, 9, 21, 25, 27,28,47], contrast baths [9, 20, 25, 27,47] and cryotherapy [69] are the most commonly used recovery strategies in rugby. Other recovery modalities investigated in the rugby literature include compression garments [20, 22–24,29], active recovery [9, 28,75] and electromyostimulation [29]. Some care must be taken when interpreting the literature on the effects of different recovery modalities in rugby, as some studies investigated the effect on acute recovery (i.e. post-match or post-training [7, 9, 20,21, 24, 28,76]), while others have focused on the effects of recovery modalities using a longer timeframe, here denominated as chronic recovery (i.e. during the training week) [20, 25, 27, 29,47]. In the acute studies, the effects of recovery on performance and physiological parameters were measured immediately post-match or

training sessions (i.e. 0 to 1 hour after) with measurements being repeated after 12 to 48 hours [7, 9, 20,21, 24, 28,76]. The chronic studies evaluated the effect of different recovery modalities from one or more rugby matches or simulated matches throughout the training week [20, 25, 27, 29,47]. In some of these studies, the athletes were exposed to recovery modalities after the match and training sessions [27, 29,47], while in others, athletes were only exposed to recovery modalities after the match [20,25]. One study measured the effects of a recovery modality during one week (i.e. cryotherapy), implemented after each training session with no competition prior [69]. Given the differences in the study designs, we decided to separate the studies that measured the acute effects of recovery modalities from competition (Table 1) and the studies that measured the effects of recovery from a rugby match during a training week (Table 2) for analysis. A brief description of the mechanisms, protocols used and outcomes of interventional studies is presented in sections below: Cold recovery modalities, Compression garments, Active recovery, and Electromyostimulation.

**Table 1.** Acute (< 48 hours) responses to different recovery strategies and protocols in the rugby literature.

Study	Sample	Strategies	Assessments/measures	Results	Overall
Beaven et al. (2013) [29]	Union, elite (super rugby), n = 16	CG minimum 3h post-training/game  CG + NMEST minimum 3h post-training/game	Questionnaires: Monday, Wednesday, Friday (6 weeks) Saliva samples for T, C and T/C: Monday, Tuesday, Thursday and Friday (6 weeks) CK: during the training blocks, and 36h post two games	Psychometric: CG + NMEST > CG (2 of 4 measures and average cumulative); T, C and T/C: No difference between groups; plasma CK training blocks: no difference between groups; CK two games: CG + NMEST > CG (post 36h)	CG + NMEST > CG
Duffield et al. (2008) [22]	Union or league, under 21, club level, n = 14	Passive  CG during and 15h post	Sprint and peak power during 2 simulated game (separated by 24h); body mass pre and post; HR and temperature pre and every 10min; muscle soreness 24h post-match 1 and 48h post-match 2; CK pre and post-match 1 and 48h post-match 2; La <sup>-</sup> pre, during and post-match	No significant difference in 20-m efforts, peak power, HR, tympanic temperature, body mass, La <sup>-</sup> and CK. Reduced perceived muscle soreness in the CG 48h post exercise	CG = PAS except for muscle soreness
Duffield et al. (2010) [23]	Union or league, club level, n = 11	Passive  CG during and 24h post	Neuromuscular performance, RPE and muscle soreness: pre, immediately post, 2h and 24h post-exercise; blood: pre, immediately post and 2h post-exercise; exercise performance: during exercise	No significant difference on 20m sprint, bounding performance, concentric force, evoked twitch properties, RPE, HR, La <sup>-</sup> , pH, CK and CRP. Reduction in aspartate transaminase and muscle soreness 24h post-exercise	CG = PAS except for muscle soreness

(Continue)

**Table 1 (continued).** Acute (< 48 hours) responses to different recovery strategies and protocols in the rugby literature.

Study	Sample	Strategies	Assessments/measures	Results	Overall
Gill et al. (2006) [20]	Union or league, elite, n = 23	Passive	3.5hr pre; 0hr, 36hr and 84hr post 4 matches	Significant differences in recovery for AR (88%), CWT (84%) and CG (85%) > PAS (39%) for 84h post. Similar magnitude post 36h	AR = CWT = CG; AR; CWT; CG > PAS
		AR (7min cycle)			
		CWT			
Hamlin et al. (2012) [24]	Union, well trained, n = 22	CG 24hr post simulated game (circuit)	Performance and blood samples: 24hr post first and second simulated game (1 week). squat DOMS: 0hr pre, 24 and 48hr each game	CG superior to placebo on: 3km time, sprint average times and fatigue, DOMS 48h post simulated game	CG > CG placebo
		Placebo CG 24hr post simulated game (circuit)			
Higgins et al. (2013) [25]	Union, U20 highly trained, n = 24	CWT	1hr pre simulated game; 1, 48, 72, 96, 144hr post (during 1 week with 3 training sessions)	Significant differences on: DOMS: CWI > CWT 48hr; PAS > CWT 72 and 96hr; RPE: CWT < PAS and CWI 96hr	CWI = PAS; CWI and PAS > CWT
		CWI			
		PAS			
Lindsay et al. (2015) [28]	Union, elite (super rugby), n = 37	PS + CG (immediately post); CWI + AR + S (day post)	2hr pre; 0hr ; 36hr post5 matches	No difference between recovering protocols post 36h for neopterin, cortisol, salivary immunoglobulin A, myoglobin	PS + CG = CWI + CG
		CWI + CG; CWI + PS ± AR and S			
		CWI + CG; CWI ± AR and S			
		CWI + CG; AR and S or nothing			

(Continue)

**Table 1 (continued).** Acute (< 48 hours) responses to different recovery strategies and protocols in the rugby literature.

Study	Sample	Strategies	Assessments/measures	Results	Overall
Suzuki et al. (2004) [70]	Union or league, collegiate, n = 15	PAS PS (60min)	Rest; 10min post-match and morning post 1 and 2 days	No differences on serum GOT, GPT, CK, and LDH; neutrophil functions between PAS and PS. PS > PAS on POMS tension score but not on depression, fatigue, anger, vigour and confusion	Physiological PS = PAS; Psychological PS > PAS on 1 of 6 POMS scores
Pointon et al. (2012) [7]	Union and league, club level, n = 10	CWI post intermittent-sprint exercise with tackling PAS post intermittent-sprint exercise with tackling	Pre and post exercise; 0, 2, 24hr post recovery (3 intermittent-sprints separated by 1 week)	Significant difference CWI > PAS 0hr post on MVC, MVA, latency and duration of M-wave, rate of relaxation, half-relaxation time and contraction duration of potentiation twitch; 2hr post on sEMG of VL/VM, muscle soreness; PAS > CWI 0hr post on blood lactate; 2hr post on MVA	CWI > PAS
Garcia et al. (2016) [21]	Union, club level, n = 8	CWI PAS AR (7min cycle)	Pre exercise and post exercise; 0, 20min (post recovery modality), 12hr	Significant differences PAS > CWI post recovery modality on agility test, CMJ and multiple CMJ; CWI > PAS 12hr post on multiple CMJ and perceptual rate of recovery	PAS > CWI (0hr); CWI > PAS (12hr)

(Continue)

**Table 1 (continued).** Acute (< 48 hours) responses to different recovery strategies and protocols in the rugby literature.

Study	Sample	Strategies	Assessments/measures	Results	Overall
Webb et al. (2013) [9]	League, elite (National rugby League), n = 21	CWI  CWT	24hr pre ; 1, 18, 42hr post 3 games (1 week interval)	CMJ height: CWT > AR post 1, 18, 42hr; CWI > AR post 42hr; CWT > CWI post 18hr; muscle soreness: CWT and CWI > AR post 1hr and 42hr; CWI > AR post 18hr; CWT > CWI post 18 and 42hr; CK: CWT and CWI > AR post 42h; CWT > AR post 1 and 18hr; CWT > CWI post 1, 18 and 42hr	CWT > CWI > AR

Under twenty (U20), pool session (PS), passive recovery (PAS), compression garment (CG), contrast water immersion (CWT), cold water immersion, (CWI), active recovery (AR), stretching (S), electromyostimulation (NMEST), creatine kinase (CK), testosterone (T), cortisol (C) Glutamate oxaloacetate transaminase (GOT), Glutamate pyruvate transaminase (GPT), Lactate dehydrogenase (LDH), countermovement jump (CMJ), rating of perceived exertion (RPE), delayed onset muscle soreness (DOMS), maximal voluntary contraction (MVC), maximal voluntary activation (MVA), surface electromyography (sEMG), vastus lateralis (VL), vastus medialis (VM), lactate (La<sup>-</sup>), bicarbonate (HCO<sub>3</sub><sup>-</sup>), C-reactive protein (CRP), aspartate aminotransferase (AST), maximal (max), average (avg), heart rate (HR).

**Table 2.** Chronic (> 48 hours) responses to different recovery strategies and protocols in the rugby literature.

Study	Sample	Strategies	Indicators of fatigue	Assessments/measures	Results	Overall
Banfi et al. (2009) [69]	Union, elite (Italian rugby union), n=10	Whole body cryotherapy for 5 days during 1 week	Immunological markers (prostaglandin E <sub>2</sub> , CRP; C3 proactivator; IgC, IgM, IgA), muscle enzymes (CK, lactate dehydrogenase), cytokines (interleukin) and adhesion molecules	Measured pre and post the week training	No significant difference in immunological markers pre and post cryotherapy except for prostaglandin E <sub>2</sub> ; significant difference for cytokines, adhesion molecule and muscle enzymes	Cryotherapy improved recovery from exercise
Beaven et al. (2013) [29]	Union, elite (Super rugby), n=16	CG minimum 3h post-training/game  CG + NMEST minimum 3h post-training/game	Psychometric, CK, testosterone and cortisol (salivary)	Questionnaires: Monday, Wednesday, Friday (6 weeks) Saliva samples for T, C and T/C: Monday, Tuesday, Thursday and Friday (pre training) (6 weeks) plasma for CK: during the training blocks, and pre and 36 post two games	Psychometric: CG + NMEST > CG (2 of 4 measures and average cumulative); T, C and T/C: no difference between groups; Plasma CK training blocks: No difference between groups; CK two games: CG + NMEST > CG (post 36h)	CG + NMEST > CG
Higgins et al. (2011) [27]	Union, highly trained, U20, n=26	CWT post both games and training sessions  CWI post both games and training sessions  PAS post both games and training sessions	Performance tests: 7x all out sprints for 7sec with 21sec recovery and 300m sprint test	Week pre and post the 4 weeks intervention: 4 games over 4 weeks + 2 training sessions per week	No differences between recovery modalities in both tests. 300m: moderate-large ES were found for CWT and less than small ES for CWI; shuttle: small ES for CWT and a negative medium ES for CWI	CWT = CWI = PAS. Trend for positive effects of CWT and negative effects of CWI

(Continue)

**Table 2 (continued).** Chronic (> 48 hours) responses to different recovery strategies and protocols in the rugby literature.

Study	Sample	Strategies	Indicators of fatigue	Assessments/measures	Results	Overall
Gill et al. (2006) [20]	Union or league, elite, n = 23	Passive AR (7min cycle) CWT CG 12h	CK (transdermal exudate)	3.5hr pre, 0hr, 36hr and 84hr post 4 matches	Significant differences in recovery for AR (88%), CWT (84%) and CG (85%) > PAS (39%) for 84h post. Similar magnitude post 36h	AR = CWT = CG; PAS < AR, CWT and CG
Higgins et al. (2012) [47]	Union, well trained U20 team, n = 24	Passive CWI post both simulated games and training sessions CWT post both simulated games and training sessions	Performance and RPE on simulated rugby game (circuit 11 stations) for 2x40min	Post the 1st and 2nd simulated game (144hr interval): 1st simulated game + 1 rest day + 3 training sessions + 1 rest day + 2nd simulated game	Performance on different tasks during the simulated game. No significant difference between groups for any dependent variable.	CWI = CWT = PAS. Trend for positive effects of CWI and CWT
Higgins et al. (2013) [25]	Union, U20 highly trained, n = 24	CWT CWI PAS	Physiological tests: sit-n-reach and circumference measures of thigh; pain perception to pressure on thigh muscles (DOMS); CMJ peak power; 10 and 40m sprint time; RPE	1hr pre simulated game; 1, 48, 72, 96, 144hr post (during 1 week with 3 training sessions)	Significant differences for: DOMS: CWI > CWT 48hr; PAS > CWT 72 and 96hr; RPE: CWT < PAS and CWI 96hr	CWI = PAS; CWI and PAS > CWT

Complement component 3 (C3), Immunoglobulin (Ig), Under twenty (U20), passive recovery (PAS), compression garment (CG), contrast water immersion (CWT), cold water immersion, (CWI), active recovery (AR), stretching (S), electromyostimulation (NMEST), creatine kinase (CK), testosterone (T), cortisol (C), countermovement jump (CMJ), rating of perceived exertion (RPE), delayed onset muscle soreness (DOMS), effect size (ES), C-reactive protein (CRP).

**Cold recovery modalities:**

Cold modalities including CWI, CWT, and cryotherapy are the most commonly used recovery strategies in rugby [7, 9, 20, 25–27, 47, 63, 69,71]. Physiological responses to cold therapies are well described in the literature [77–80]. Briefly, a cold environment, whether induced by water or air temperature, decreases skin, core and muscle temperature. The reduction in tissue temperature leads to vasoconstriction and consequently a decrease in swelling and acute inflammation from muscle damage [77–79]. Moreover, the use of cold therapies also contributes to a reduction in nerve conduction properties and a decrease in muscle spasm and pain [77–79]. Thermotherapy (i.e. immersion in hot water) increases vasodilation, leading to an increase in blood flow and facilitation of oxygen and antibody supply, metabolite clearance and reduction in muscle spasm and pain [77–79]. When combined, cold and hot therapies result in both vasoconstriction and dilation that lead to changes in blood flow and reduction in swelling, inflammation and muscle spasm [77–79]. The hydrostatic pressure-induced changes in blood flow from CWT and CWI further promote removal of the by-products of energy production, and nutrient transportation [81,82]. Cold modality protocols reported in rugby specific literature can be found in Table 3.

**Table 3.** Cold protocols for recovery from rugby training and competition within rugby literature.

Study	Strategy	Temperature (°C)		Time (sets x minutes)
		Cold	Hot	
Banfi et al. [69]	Cryotherapy			30sec at -60°C followed by 2min at -110°C
Higgins et al. [27], Webb et al. [9]	Cold baths	10-12		1 x 5min
Higgins et al. [47], Higgins et al. [25]	Cold baths	10-12		2 x 5min
Lindsay et al. [28]	Cold baths	8-12		1 x 10min
Pointon et al. [7], Garcia et al. [21]	Cold baths	~9		2 x 9min
Gill et al. [20], Webb et al. [9]	Contrast	8-10	40-42	3x (1min cold : 2min hot)
Higgins et al. [27]	Contrast	10-12	38-40	7x (1min cold : 1min hot)
Higgins et al. [47], Higgins et al. [25]	Contrast	10-12	38-40	5x (1min cold : 1min hot)

Equivocal results have been found regarding the acute effects of cold therapies on recovery (Table 1). While some studies demonstrated a beneficial effect of cold therapies [7, 9,20,21], others failed to find benefits [25,28]. Pointon and Duffield [7] observed a beneficial effect of CWI in comparison to passive recovery (PAS) on knee extensors maximal voluntary contraction (MVC) and delayed onset muscle soreness (DOMS) (Table 1). However, differences were only evident for up to 2 hours post exercise. Additionally, no differences were found in muscle damage between recovery modalities at any time point (0, 2 and 24 hours post exercise). As suggested by the authors, the acute improvements in the MVC after CWI were associated with the interaction between alterations in the state of peripheral contractile ability and enhanced skeletal muscle recruitment via increased central activation [7]. Given that

no changes between the CWI and the PAS group were observed for the markers of muscle damage, the authors suggested that the differences in the level of DOMS were possibly associated with the placebo effect of CWI [7]. Controversial results were found by Garcia et al. [21] who observed a decrease in neuromuscular performance after a rugby-specific exercise protocol followed by CWI (compared to a passive control), measured by countermovement jumps, 30 seconds of continuous jumping and an agility T-test (Table 1). However, 12 hours later, the authors observed a greater increase in the 30-second continuous jumping test and perceived rate of recovery in the CWI group [21]. Webb et al. [9] also verified a greater benefit of CWI and CWT on jumping performance, DOMS and CK clearance measured 1, 18 and 42 hours post-match in comparison to an active recovery group (Table 1). Furthermore, the authors reported a superiority of CWT in comparison to CWI (Table 1), attributing the differences observed to the exposure to duration of hydrostatic pressure (9 minutes in CWT and 5 minutes in CWI) [9].

Greater increases in CK clearance in CWT compared to PAS were also reported by Gill et al. [20]. Notwithstanding, the authors found no differences in CK clearance between any recovery modality (Table 1). While the aforementioned studies on the effects of cold modalities on neuromuscular function reported a beneficial effect of CWI and/or CWT, the timeframes associated with the benefits remain equivocal [7, 9,21]. The different type of exercise (i.e. multi-joint exercise [9,21] and single-joint exercise [7]) and the type of contraction (i.e. jumping [9,21] and isometric maximal voluntary contraction [7]) used to assess neuromuscular function may explain, at least in part, the different findings.

In contrast to previous findings, Higgins et al. [25] reported that there were no beneficial effects of CWI or CWT on acute recovery. In their study, the authors compared the effects of PAS, CWT and CWI on neuromuscular performance and RPE, 1, 48, 72, 96 and 144 hours following a simulated game (Table 1). No differences were found in the acute recovery window (pre the next training session) between any recovery strategies. However, as demonstrated in the study by Pointon and Duffield [7], a lack of information between 1 hour and 48 hours post-training may be an excessively long window to allow adequate assessment of the acute effect of a recovery modality (Table 1). Moreover, the results from the study by Webb et al. [9] demonstrating that differences between cold modalities were more evident 18 hours post-match also demonstrate that an intermediate testing session should have been conducted in the study by Higgins et al. [25] if the goal was to understand the acute effectiveness of different recovery modalities. Webb et al. [9] observed a beneficial effect of CWI and CWT in neuromuscular performance, DOMS and CK after 42 h (Table 1). The differences in the population used for study (i.e. elite vs. under-20s), and the fact that Higgins et al. [25] used a simulated game in comparison to an official rugby league match used by Webb et al. [9] can explain the conflicting findings (Table 1). No differences were observed by Lindsay et al. [28] when comparing the effects of a combination of varied recovery modalities (including CWI) on markers of psychophysiological stress immediately and 36 hours post-match (Table 1). However, the combination of different recovery modalities (both immediately post-match and on the day after) and the absence of a control group make it difficult to understand the efficacy of the recovery modalities.

Regarding cold recovery modality protocols, studies utilized between 5 and 18 minutes of total exposure to cold water (8-12 °C) in CWI and 3 to 7 minutes of total exposure to cold water in CWT (Table 3). Moreover, in CWT the cold to hot ratio (cold:hot) varies from 1:1 to 1:2, with temperatures ranging between 38-42 °C (Table 3). The dose-response relationship between the duration and enhanced recovery after intermittent exercise is still to be investigated. The beneficial effects of CWT in comparison to CWI are likely to be associated with the differences in the total exposure time to the hydrostatic pressure of being immersed in water [9]. Studies where the total exposure time to hydrostatic pressure was superior in CWT in comparison to CWI (CWT 14 minutes vs. CWI 5 minutes [27]; CWT 9 minutes vs. CWI 5 minutes [9]) demonstrate a beneficial effect on recovery for the CWT group. In contrast, when the immersion times for the groups were equal (CWT and CWI 10 minutes) the CWI intervention was either superior [25] or equal [47]. Given the aforementioned results, further research should aim to equalize exposure time to hydrostatic pressure between interventions (CWI and CWT).

The time after exercise to implement cold modalities is also an important aspect of the protocols implemented [39,83]. Research by Brophy-Williams et al. [84] with collision team-sport athletes (i.e. Australian Rules football and ice-hockey) revealed that immediate post-exercise (i.e. high-intensity exercise session) cold water immersion resulted in a 79% likely benefit when compared to a 3-hour delayed CWI session. Additional research is needed to confirm these findings and investigate other intervals of time between exercise and the implementation of the cold treatment.

Although literature on the efficacy of cold modalities on acute recovery from rugby is lacking, results indicate that these strategies can play an important role in recovery. This has been demonstrated by increases in neuromuscular function [7, 9,21], increases in perceived recovery [21], decreases in DOMS [7,9] and decreases in CK [9,20]. The results from the referenced studies can be found in tables 1 and 2. Similar findings have been reported in other sports (e.g. soccer [39]). Moreover, additional studies comparing the effects of CWI and CWT are necessary.

When the time for recovery between training sessions is limited, CWI can be implemented as it aids diminishing fatigue. Based on the reviewed literature, we would recommend a duration of ~10-12 minutes with temperatures of 8-12 °C implemented immediately post-exercise. If CWT is to be implemented, we would recommend 3 to 7 minutes of total exposure to cold water (8-12 °C) with a cold to hot (38-42 °C) ratio of 1:1 or 1:2.

With regard to chronic responses and adaptations from the usage of cold therapies, the results are also inconsistent. Banfi et al. [69] reported a significant increase in anti-inflammatory cytokines with a simultaneous decrease in pro-inflammatory cytokines and muscle enzymes (creatine kinase and lactate dehydrogenase) following a week of rugby training when athletes were exposed to cryotherapy (5x week) (Table 2). The authors concluded that short-term cold air exposure improves recovery from EIMD (Table 2). Gill et al. [20] also found a clear benefit on CK clearance for CWT when compared to PAS 84 hours after an elite rugby match (Table 2). Higgins et al. [47] found no differences between CWI or PAS on performance and rating of perceived exertion between two rugby-specific simulated games separated by 1 week (Table 2).

However, the authors found a trend for beneficial effects of CWI. Higgins et al. [25] observed no improvements in a group exposed to CWI in comparison to PAS for CMJ and sprinting performance, measured 1, 48, 72, 96 and 144 hours following a simulated game (Table 2). However, the authors found that CWI was superior to CWT on DOMS measured 48 hours following the first simulated match. The authors concluded that CWT had little benefit in enhancing recovery in young rugby athletes.

Higgins et al. [27] also found no major differences between CWT, CWI and PAS on a 300-m run and a phosphate decrement test (seven sprints of 7 s with 21 s of rest between each repetition) post four weeks of training and competition (Table 2). The 300-m and the phosphate decrement test were used to mimic the anaerobic capacity demands during sustained and repeated bouts observed in rugby [14, 16,85]. The authors observed a large effect size for CWT in the 300m test. For the shuttle test, the authors found a negative medium effect size for CWI. Perhaps the use of tests that are susceptible to substantial human error given the methodology used may in part explain the differences found [86,87]. Sprint times were measured with a stop watch (systematic error and interrater reliability for 30m running times of 0.07 and 0.1 seconds, respectively [87]) and sprint distances were estimated visually with markers set every 2m being used as reference.

While the majority of the literature supports cold therapies for enhancing acute recovery [7, 9,20,21], some authors argue that the effect of cold exposure post-exercise may blunt chronic adaptation by the muscles [88–90]. Amongst other factors, this is possibly due to the reduction in muscle blood supply that occurs from cold application after exercise [91]. Studies have demonstrated a decrease in the anabolic signalling

pathway activity after CWI was implemented post-exercise, and consequently an attenuation in muscle size adaptations was reported [88], suggesting that an adequate blood supply is essential for protein synthesis [92].

However, some care should be taken when interpreting results from these experiments and their practical application for a team sport such as rugby. Firstly, some of the cold protocols used are not similar to those used in rugby (Table 3). For example, in the study by Yamane et al. [93], the authors used a protocol consisting of 2 x 20 minute bouts in 5 °C cold water. This is double the time implemented in the longest protocol used in the rugby literature (2 x 9 minutes [7]). Moreover, the temperature is considerably lower than the 8-12 °C range commonly used in rugby (Table 3). Secondly, the training level, specifically the strength training background of the subjects who were untrained or recreationally trained [88, 90,93], is not comparable to the training background of the rugby athletes that participate in studies where the chronic effects of cold therapies were assessed [20, 25, 27, 47,69]. Furthermore, the training load used in these studies is much less in comparison to the total load from a traditional training week of a rugby athlete, especially at a professional level. Thirdly, in some of the chronic studies the authors fixed the training volume and intensity in both the control and cold groups. If cold modalities work by allowing a greater training quality and/or quantity in the subsequent training sessions, then the fact that training intensity is fixed and matched in these studies does not allow us to determine whether enhanced training quality and or quantity in subsequent sessions in the cold group may in fact outweigh any possible blunting effect. Lastly, during the in-season period, the goals for a rugby athlete are less likely to be increases in muscle mass [6, 43,94,95].

Normally, increases in strength and power are desirable, therefore, alactic efforts (i.e. training with high loads and/or high velocity of displacement for 1-6 repetitions) are implemented rather than hypertrophic methods [6, 43,94,95]. In order to achieve maximal neural stimulus (e.g. peak power), training sessions must be performed with athletes being in a fresh, non-fatigued state [45]. As acute responses from cold recovery modalities seem to enhance the readiness (e.g. neuromuscular performance) of rugby athletes post training and competition, when the goal of the following session is to produce high power and peak force outputs, the inclusion of such modalities is recommended [7,9]. However, as cold therapies may lead to a decrease in hypertrophy signalling pathways and activation of satellite cells, when the goal is to increase muscle mass (e.g. off-season, younger athletes) one should consider the use of such recovery modalities [88]. Future research should aim to compare the acute (i.e. increased neuromuscular function) and long-term effects (i.e. muscle size and performance) of implementing cold modalities after rugby training and competition.

The conflicting findings and lack of research that can be found in the rugby literature regarding the chronic effect of different cold modalities make it somewhat difficult to draw conclusions and make practical recommendations. Furthermore, several limitations of the methodology used were identified in the studies that assessed the chronic effects of cold recovery modalities. However, there are some indications that exposing individuals to cold recovery modalities may blunt chronic adaptations to training, particularly in relation to changes in muscle size. For this reason, cold modalities should be restricted to periods when the time for recovery is limited and/or to periods when sessions with high workload and power outputs are desirable.

## Compression garments (CG):

Compression garments are commonly used by rugby athletes during and/or following training or competition [20, 22–24,29]. Briefly, the compression exerted by the garments may contribute to the reduction of swelling and inflammation from muscle damage by creating an external pressure that might reduce space for swelling, haemorrhage and haematoma [96–98] (Table 4).

**Table 4.** Compression garment protocols for recovery from rugby training and competition used in the rugby literature.

Study	Characteristics	Pressure	Application	Duration
Beaven et al. [29]	Commercial full-length lower-body compression	n.a.	Post-training	Minimum of 3hr; preferable overnight
Duffield et al. [22]	Commercial full-length lower-body compression	n.a.	During training and post-training	Overnight (15hr post-training)
Duffield et al. [23]	Commercial full-length lower-body compression	n.a.	During training and post-training	24hr post-training
Gill et al. [20]	Commercial full-length lower-body compression	n.a.	Post-match	Overnight (12hr post-match)
Hamlin et al. [24]	Commercial full-length lower-body compression	~8 to 13 mmHg	Post-training	24hr post-training
Lindsay et al. [28]	Commercial full-length lower-body compression	n.a.	Post-match	Post-training until next training day

Not available (n.a)

The effects of CG on acute recovery from rugby are equivocal. Hamlin et al. [24] found benefits in 3-km run time and repeat sprint time following 24 h of using CG in comparison to a placebo. In contrast, Duffield et al. [22] found no differences between CG and PAS for repeated sprint times performed prior to and post each half of a circuit that simulated a rugby match. The authors also found no differences in peak power output from a single-man scrum exercise performed immediately following the

repeated sprint protocol. When the circuit was repeated 24 h later, no differences were detected in performance between recovery strategies [22]. We speculate the fact that Duffield et al. [22] used an amateur population sample might explain the difference in results, as the intensity, and therefore the EIMD, might be lower in this lesser-trained group, and therefore allow athletes to recover between the simulated matches. Duffield et al. [23] found no differences in performance during an exercise comprising a 20-m sprint and 10-m double leg bounds or in peak force of knee extensors/flexors when CG and PAS were compared [23]. The contradictory findings from Duffield et al. [23] in comparison to the findings from Hamlin et al. [24] can potentially be justified by the differences in training load. The study by Duffield et al. [23] included athletes exercising for 10 minutes and the study by Hamlin et al. [24] had the athletes exercising for approximately 84 minutes. Moreover, as stated by Hamlin et al. [24] the failure of these studies [22,23] to find small but worthwhile changes in performance can be attributed to the small sample size and/or the variability in the performance assessments. When comparing CK concentration following an elite rugby match, Gill et al. [20] observed that CGs were as effective as AR and CWT. Athletes demonstrated a reduction in CK 36 and 84-hours post, compared to PAS. Similar results were found by Hamlin et al. [24] who observed a superior CK clearance following a simulated game in well-trained athletes who used CG, when compared to a placebo garment. Again, Duffield et al. [22] and Duffield et al. [23] found no benefits with respect to CK levels when using CG. As suggested, the differences in the training load between the studies of Duffield et al. [23] and Hamlin et al. [24] can explain the differences seen in the muscle damage markers. Moreover, differences in the training status of the populations (amateurs vs well-trained) in the studies of Duffield et al. [22,23] and

Hamlin et al. [24] might further explain the contradictory findings.

One aspect that seems to be clear is the effect of CG on perceived muscle soreness [22–24]. These findings are in agreement with recent reviews on CG which reported moderate benefits (Hedges'  $g = 0.403$  [99]; effect size = 0.47[100]) on DOMS in comparison to control [99,100]. In summary, the recommendations for the use of CG to aid physiological (e.g. CK clearance) and performance (e.g. sprint performance) remain unclear; however, a beneficial effect on perceived recovery is likely to occur. Given this, and since CG are inexpensive and non-invasive, they can easily be implemented during exercise and 15 to 24 h post-training and competition as a recovery strategy by rugby athletes [22–24].

### **Active recovery (AR):**

Studies that have implemented AR following rugby matches present conflicting findings. Gill et al. [20] observed a beneficial effect of a short term cycling protocol (7 minutes at 150 W) on muscle damage measured by CK obtained 36 and 84 h following an elite rugby match in comparison to PAS. The authors found no differences between AR and CWT or CG. Conversely, using the same AR and CWT protocols, in another group of elite rugby athletes, Webb et al. [9] observed the AR protocol to be less effective on improving performance, muscle soreness and CK in comparison to CWT and CWI. While the effects of a short AR protocol, performed immediately following a rugby match, present conflicting results in terms of CK clearance [9,20], the work by Webb et al. [9] was the only study that addressed other parameters such as neuromuscular function, which as previously discussed is a more sensitive and accurate marker of both the magnitude and time-course of EIMD, or muscle soreness. The

results from that study demonstrated a lower effect of AR in jumping performance and muscle soreness measured 1, 18 and 48 h post-match in comparison to CWT and CWI (Table 1) [9]. Additionally, in their study, no control group was used, which poses a major limitation in understanding the efficacy of AR in comparison to PAS [9].

To the best of our knowledge, the only study that evaluated the efficacy of AR performed on the day following exercise was the study performed by Suzuki et al. [70]. In their study, the authors used an AR protocol that consisted of one hour of low intensity dynamic exercises performed in a pool once a day on two recovery days. No differences were found in muscle damage-related enzymes, including CK, when compared to PAS. However, a positive effect of AR on the profile of mood states (POMS) tension score was reported by the authors. Results from the study by Lindsay et al. [28] suggest that immediate post-game recovery strategies (AR and CG or CWI and CG) may be more important to psychophysiological parameters than the post-day match strategies. However the more ecological-setup (i.e. mixture of strategies) used by Lindsay et al. [28] makes it difficult to assess the efficacy of each individual recovery strategy. In summary, literature regarding the effect of AR performed either immediately following a rugby match or on the subsequent days is lacking. Future research should address the efficacy of AR performed immediately following a rugby match compared with the next day on various physiological and performance parameters.

### **Electromyostimulation (EMS):**

To the best of our knowledge only one study has investigated the effect of EMS on recovery in rugby athletes [29]. Briefly, EMS consists of a series of electrical stimuli

being delivered superficially using electrodes on the skin [101], resulting in enhanced muscle pump action and consequently, increased venous blood flow [101–103]. Beaven et al. [29] compared the effects of CG + EMS with CG alone for 6 weeks during the in-season training period in elite rugby athletes. No differences between training protocols were found for hormonal responses (testosterone, cortisol and T/C ratio) or plasma CK across training blocks. However, CG + EMS was shown to be beneficial for CK clearance measured 36 hours following two games and also on some psychometric measures (i.e. energy levels and enthusiasm) assessed during the week-training cycle. In summary, when combined with CG, EMS may provide some benefits to both acute and chronic recovery from rugby training and competition. Future research should dissociate EMS from other recovery strategies in order to understand the effect of EMS in isolation rather than the combination of EMS with other modalities. The inclusion of a control group is also recommended to better understand the effects of EMS.

## **Conclusion**

Literature that has evaluated the effect of different recovery modalities following rugby competition and/or training is limited. Furthermore, there are even fewer studies describing the chronic recovery response (i.e. one or more weeks) when compared to the acute recovery response (i.e. hours or days). However, such differentiation should be made as a greater acute recovery may [27,47] or may not [25,27] result in greater chronic adaptation.

## **Acute responses to recovery modalities:**

The acute effectiveness of different recovery strategies currently utilized in rugby is varied. Cold modalities seem to have a beneficial effect on CK clearance [9,20], neuromuscular performance [7, 9,21], and DOMS [7,9]. Contrast water immersion seems to be more beneficial in comparison to CWI for neuromuscular performance [9] and CK clearance [9,20]. For reducing DOMS, CWT seems to be more effective when compared to CWI in the short-term (i.e. 18 h [9]), with findings being inconsistent over a longer timeframe (i.e. 42-48 h [9,25]). However, differences in study populations and methodology (i.e. elite actual rugby match [9] and under-20s simulated rugby match [25]) may explain the contradictory findings. Likewise, differences in the total exposure time to hydrostatic pressure may also explain the differences observed between CWT and CWI [9]. Compression garments demonstrate a superior effect in comparison to control for reducing DOMS [22–24]. However, contradictory results have been reported on CK clearance [20,22–24], which can be associated with the limitations of this muscle damage marker briefly discussed previously. Moreover, the relationship between CG and neuromuscular performance is contradictory [22–24]. When combined with CG, EMS can enhance recovery in comparison to CG without EMS [29]. However, this superiority is limited to psychometric measures and rate of CK clearance [29]. The effect of active recovery from rugby matches seems to be limited to enhancements in CK clearance [20].

## **Chronic adaptation and recovery modalities:**

While cold modalities seem to have a positive effect on chronic recovery (i.e. during a longer timeframe, such as a training week) from muscle damage [20,69], their effects on performance, DOMS and RPE are not clear [25, 27,47]. Also, there are limited studies analyzing the chronic effects of these recovery strategies (i.e. cold modalities) on anabolic signalling or muscle size [88]. To the best of our knowledge, no study has been performed investigating the effect of cold modalities on chronic muscular adaptation in rugby. Given the clear relationship between muscle mass, maximum strength and power [46,104], and the importance of these qualities for rugby [94,95], it seems to be of utmost importance to understand the effect of cold modalities during periods when increasing muscle mass is a primary goal (e.g. pre-season) [94,105]. As well as cold modalities, AR and CG demonstrated a beneficial effect on the CK clearance rate during a training week cycle (i.e. 84 h following four matches) when compared to a PAS group [20].

## **Limitations and recommendations for future research:**

Many conflicting results and conclusions can be drawn from the recovery literature performed in the rugby context. Although one can understand the ecological validity used in some studies (i.e. combination of various recovery strategies [28,29]), these do not allow for a clear understanding of the specific individual recovery modalities. Moreover, studies addressing the physiological mechanistic responses of different recovery modalities in rugby are limited [7]. Further research should expand the findings to an elite rugby population and explore the mechanistic effects of different

recovery modalities post-match. When the goal is to observe the effects of recovery strategies on acute recovery, athletes should be assessed within short periods of time (e.g. 0, 12, 24, 36 and 48 h post) and no training should be performed during that period [25]. The same scenario must occur if one wants to understand the effects of a rugby match on physiological or psychological variables. Although it can be unrealistic to have athletes refrain from training over a longer period of time (i.e. one week), this can be investigated following the last game of the season. Another factor that has been criticized is that a few studies have no control group [9,28]. While it can be unethical to have a group of elite athletes performing no recovery modality (i.e. PAS) post-match, a good option would be again to choose the week following the last game of the season. Nevertheless, the reduced number of samples used for data collection (i.e. just one match) would lead to further limitations.

The effects of rugby competition and training on the lower body are widely studied [7, 9–11, 24,25, 30,31,106]; however, only one study assessed the effects on the upper body [10]. The authors used a CMJ and plyometric press-ups to measure lower and upper body fatigue during an intensified week cycle with three collegiate rugby matches over a 5-day period [10]. The CMJ peak power was significantly lower 24 h following the first match, and 2, 12 and 36 h following the second match. No changes were found for CMJ peak force. For the plyometric press-ups, significant changes were observed for peak power 12 h following the second match and for peak force 2, 12 and 36 h also following the second match [10]. These differences in upper versus lower body performance can provide important information when designing training programs e.g. an individual whose lower body has not recovered fully may still

participate in upper body training and vice-versa. Given that differences have been found between upper and lower body [10], future research concerning recovery modalities and fatigue monitoring should distinguish between body regions. Lastly, studies performed with rugby athletes are limited to a minority of recovery modalities. Given that a plethora of other recovery modalities are being used by rugby athletes (Francisco Tavares, Phil Healey, Tiaki Brett Smith & Matthew Driller; unpublished observation), future research should attempt to find if there are any beneficial effects of using such recovery modalities.

### **Practical recommendations:**

Cold water modalities are an effective strategy to recover from rugby training and competition, as demonstrated by CK clearance [9,20], enhanced neuromuscular function [7, 9,21], and decreased DOMS [7,9]. Therefore, we would recommend both CWT and CWI for coaches and practitioners aiming to increase the quality of subsequent training sessions, occurring within a short timeframe (i.e. 12-42 h). However, given the recent evidence on the acute decrease in the anabolic signalling pathway activity and attenuation in muscle size adaptations [88], consideration should be given to the usage of cold modalities and perhaps restricted to use following specific sessions (e.g. post rugby matches and hard training sessions) and when the time to recover is limited (i.e. < 48 hours). Compression garments are an inexpensive, non-invasive and effective modality to reduce the DOMS associated with rugby [22–24]. We would recommend using CG for athletes during rugby training and also during the recovery period [22–24]. Moreover, the combination of CG with EMS may provide

additional benefits to recovery throughout the training week (i.e. enhanced psychometric benefits and CK clearance) [29].

## CHAPTER THREE

### **The usage and perceived effectiveness of different recovery modalities in amateur and elite rugby athletes**

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Elite team-sport training has a greater volume, frequency, and intensity in comparison to amateur training. Given this, elite athletes are expected to implement recovery modalities to a greater extent than amateur athletes. In addition, greater access (e.g. time and equipment) in the elite environment may facilitate the implementation of recovery modalities. Conversely, a lower training load and frequency observed within the training week of amateur rugby may limit the rationale for implementing recovery modalities. **Study Two** aimed to understand what recovery modalities are perceived as more effective, and the frequency of their use by amateur and elite rugby athletes. While **Study One** demonstrates the potential of different recovery modalities implemented in rugby, **Study Two** allowed us to determine the actual usage and perceived effectiveness of different recovery modalities within elite rugby athletes. The findings of both of these studies was used to guide and design the subsequent studies of this doctoral project on the effects of cold water immersion in elite rugby athletes.

## Abstract

**Background:** The use of recovery modalities to help enhance recovery is popular among athletes. However, little is known about the usage of various recovery modalities and the perception of their benefit amongst different level athletes. Therefore, the purpose of this study was to compare the usage and perceptual understanding of different recovery modalities between elite and amateur rugby athletes. **Methods:** Fifty-eight amateur ( $n = 26$ ) and elite ( $n = 32$ ) rugby athletes completed a questionnaire designed to determine the usage and the perception of 15 different recovery modalities. A 5-point Likert scale was used to examine the perceived importance of recovery and effectiveness of each recovery modality. The number of different recovery modalities, and the number of times each player used each recovery modality per week was also obtained through the questionnaires. The total number of times an athlete used a recovery modality was calculated by summing the number of times each recovery modality was used per week. **Results:** No differences were found between groups (elite:  $5.0 \pm 0.2$ ; amateur:  $4.9 \pm 0.3$ ) for the perceived importance of recovery to enhance performance. When comparing the effectiveness of each recovery modality, the elite group perceived active recovery, massage, pool recovery, additional sleep and stretching to be significantly ( $p < 0.05$ ) more effective in comparison to the amateur group. No significant differences were found for any other recovery modality. There was a significantly greater amount of recovery modalities used and also a higher frequency of use per week in the elite group ( $p > 0.05$ ). **Conclusion:** Although no differences were found for the perception of the importance of recovery, elite rugby athletes used significantly more recovery modalities and implemented recovery

modalities more often in comparison to amateur rugby athletes.

Keywords: Active recovery, stretching, cold baths

### **Key Points**

No differences were found for the perception of the importance of recovery between groups.

Elite rugby athletes use significantly more recovery modalities (~8 vs 3) in comparison to amateurs.

Elite rugby athletes implemented recovery modalities more often (~25 vs ~6 times per week) in comparison to amateurs.

Elite rugby athletes perceived 6 out of 11 recovery modalities to be more effective in comparison to amateurs.

## **Introduction**

Rugby (union and league) is a high-intensity team sport played in several countries worldwide [13,14]. Like most team sports, rugby is intermittent, with bouts of high intensity efforts interspersed with low intensity activities or rest [1, 3,15]. Moreover, the collision-based activities like tackling, static holds, scrums, rucks and mauls, leads to remarkable muscle damage to the extent that muscle damage markers, such as creatine kinase, can remain elevated for up to 120 h post-match [18,19]. However, a prolonged period of muscle damage is more likely to result from the cumulative effect of training (i.e. repeat sessions occurring during the training week), rather than exclusively from a single rugby match [107].

At the elite or professional level, rugby training often occurs less than 48 h following a match with athletes training for two or more consecutive days during a training week [6], therefore, it is likely that the players' physical readiness is compromised [31,52,53]. An insufficient recovery period can lead to an excessive level of accumulated fatigue over the week that may lead to under-performance on match day [10,11] and undesirable fatigue states over a training phase [12]. In order to reduce the harmful effect of fatigue and allow athletes to recover faster, athletes regularly implement different recovery modalities in their routines [9, 20, 24, 29, 47,71]. Previous literature has identified stretching and cold modalities as the most used recovery strategies implemented by elite rugby athletes [42]. In agreement with previous research, our recent review on recovery modalities identified cold therapies (e.g ice-baths) as the most frequently used recovery strategy reported in the rugby-specific research literature [107]. This is not surprising, given the high-contact nature

and consequent muscle damage associated with rugby training and competition.

When the perceived effectiveness of different recovery modalities between club, National and International level athletes (hockey, rugby, netball and soccer) was compared, no differences were found between club and National or International level athletes [38]. However, no information was provided about the perceived effectiveness of recovery modalities within each sport. To the best of our knowledge, no study has compared the usage and perceived effectiveness of different recovery modalities between different competition levels in rugby.

The training load and training workload density are likely to differ between elite [6, 8, 19,35] and amateur athletes [25,27]. Moreover, amateur rugby matches lead to lower levels of muscle damage in comparison to professional rugby matches [7, 18–20, 24, 55,70]. Therefore, the purpose of this study was to compare the usage and perceived importance of recovery modalities between elite and amateur rugby athletes. Moreover, the weekly training schedule of the elite and amateur rugby athletes surveyed was collected in order to determine if training load influenced the usage and perceived importance of recovery modalities.

## **Methods**

### *Participants*

Fifty-eight male rugby athletes volunteered to participate in the current study. A questionnaire was completed by 32 elite rugby athletes all from the same team and by 26 amateur rugby athletes who were all members of the same team (n = 26) (Table 1). All athletes volunteered to answer the questionnaire and completed the

questionnaire during the in-season phase of training. Written informed consent was obtained from each participant, and ethical approval was obtained from the Institution's Human Research Ethics Committee.

**Table 1.** Participant demographics. Data shown as means  $\pm$  SD. \* Represents significant differences between groups ( $p < 0.05$ ).

	Elite (n = 32)	Amateur (n = 26)
Age (years)	24.4 $\pm$ 2.9	25.6 $\pm$ 4.9
Time playing rugby (years)	16.1 $\pm$ 4.9	12.4 $\pm$ 5.7*

### *Procedures*

The questionnaire was designed to gather information on athletes' usage and perceived effectiveness of different recovery modalities. In addition to background information relating to age and training age, the questionnaire contained questions about the usage and perceived effectiveness of 15 different recovery modalities (cold baths, active recovery, hot baths, massage, contrast baths, compression garments, sauna, pool recovery, cryotherapy, electromyostimulation, additional sleep, nonsteroidal anti-inflammatory drugs (NSAID), stretching, hyperbaric oxygen therapy, peristaltic pulse dynamic compression (PPDC)) and also a question about the importance of recovery to enhance performance. To answer these questions, a 5-point Likert scale (1 = not important at all, 2 = not very important, 3 = neutral, 4 = somewhat important, 5 = extremely important) was used. The recovery modalities were chosen from previous studies in rugby or rugby league [107] and from the review papers of Barnet [37] and Vaile, Halson, & Graham [108]. In order to clarify the different recovery modalities, a picture of each recovery modality was shown alongside the questionnaire. Participants were also instructed to indicate when they had not experimented nor felt familiar enough (N/E) with certain modalities. From the questionnaire, the number of different recovery modalities each player used per week was recorded. We also calculated the total number of times that athletes used all recovery modalities by summing the number

of times each recovery modality was used per week.

Additional information about the typical in-season training week (with a match on a Saturday) was collected from the strength and conditioning coaches for the amateur and professional groups (Table 2). Information relating to the duration and the type of the session (i.e. technical-tactical session, conditioning session, gym session), the intensity of on-field (i.e. high, moderate, easy intensity) and gym sessions (i.e. strength, power, hypertrophy) was gathered.

**Table 2.** Typical in-season training week schedule of elite and amateur rugby players. Resistance training, conditioning and technical-tactical duration (minutes) and intensity or type of training is described.

Elite							
	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
Morning	WB (30'; P)		UB (75'; S); TT (60-90'; Low)	TT (30'; Moderate); LB (75'; S); TT (30-45'; High)	Con (30'; Low)	TT (30'; Low); TT (15-30'; Moderate); WB (60'; P)	TT (60'; Moderate)
Afternoon	Game			TT (75-90'; High)		TT (75-90'; High)	
Evening							
Amateur							
	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
Morning							
Afternoon	Game						
Evening			UBRT (60'; SS + P/HT); TT (40'; Low)	LBRT (60'; SS + P/HT); TT (60-90'; High)		WB (60'; SS+P); TT (75'; Moderate)	

\* Whole body resistance training (WB); Upper body resistance training (UBRT); Lower body resistance training (LBRT); Strength session (SS); Hypertrophy session (HT); Power session (P); Technical-tactical session (TT); Conditioning session (Con). In resistance training sessions, “+” signify a combination of methods of training and “/” means that one of the methods is implemented. For example, “S + P/HT” signify that in the session the group use strength method together with either a power or hypertrophy method.

### *Statistical Analysis*

The data collected was analyzed using SPSS (Version 22.0, SPSS Inc., IBM, Chicago). The Shapiro-Wilk test was performed to check the condition of normality for each variable. An independent T-test was used to compare differences between elite and amateur for age. A Mann-Whitney U test was used to compare differences between elite and amateur for age, training age, number of recovery modalities used, total number of times all recovery modalities were implemented per week, perceived effectiveness of each recovery modality, perceived importance of recovery and number of times each modality was implemented per week. Magnitudes of the standardized effects between groups were calculated for the perceptual effectiveness of each recovery modality using Cohen's *d* and interpreted using thresholds of 0.2, 0.6, 1.2, 2 and 4 for *small*, *moderate*, *large*, *very large* and *extremely large*, respectively [109]. For the weekly usage of each recovery modality, only the recovery modalities that were used by more than 20% of athletes from both groups were compared. For the perceptual effectiveness of each recovery modality, only the recovery modalities that were familiar to more than 20% of athletes from both groups were compared. In order to compare the differences between the number of elite and amateur athletes using each recovery modality, a Chi-Square test was used. A significance level of  $p < 0.05$  was implemented for all statistical tests. Results are presented as means  $\pm$  SD, except for effect size statistics, which are presented as means  $\pm$ 90% confidence limits. Where the  $\pm$ 90% confidence limit overlapped *small* positive and negative effects ( $\pm 0.2$ ), the effect was deemed to be *unclear*.

## Results

Significant differences ( $p < 0.05$ ) were found for rugby training age but not for age between the elite and amateur group (Table 1). The total training time during a traditional in-season week for the elite group is composed of 3:15 to 3:45 (h:min) in the gym, 6:15 to 6:45 (h:min) of on-field rugby practice, 30 min of low intensity conditioning and a rugby match. In contrast, the amateur group typically train for approximately 3:00 (h:min) minutes in the gym, 2:55 to 3:25 (h:min) of on-field rugby practice and play one rugby match (Table 2).

No differences were found between groups (elite =  $5.0 \pm 0.2$ ; amateur =  $4.9 \pm 0.3$ ) on the importance of recovery for enhancing performance. When comparing the effectiveness of each recovery modality, the elite group perceived active recovery, massage, pool recovery, additional sleep and stretching to be significantly ( $p < 0.05$ ) more effective in comparison to the amateur group (Table 3). No significant differences between groups were found for any other recovery modality (Table 3). The differences between groups were associated with the following effect sizes, with higher ratings in the elite group [109]: *large* effect size for active recovery, compression garments, pool recovery, stretching and PPDC; *moderate* effect size for cold water immersion, massages and additional sleep; *small* effect size for sauna; and *trivial* effect size for hot baths and contrast baths (Table 3). A *small* effect size with higher ratings in the amateur group was found for the sauna modality (Table 3). Data from cryotherapy, electromyostimulation, NSAID and hyperbaric oxygen therapy was not included in the statistical analysis as less than 20% of each group were familiar with such techniques.

**Table 3.** Mean  $\pm$  SD for usage and ratings of perceived effectiveness of different recovery modalities between elite and amateur rugby athletes. \* Represents significant difference ( $p < 0.05$ ) between groups.

Recovery modality:	Number of athletes familiar with each modality		Perceived effectiveness (1-5)		Amateur – Elite Effect size ( $\pm 90\%$ CI)
	Elite	Amateur	Elite	Amateur	
Active recovery	32	26	4.4 $\pm$ 0.7	3.1 $\pm$ 0.9*	1.72 $\pm$ 0.17 ( <i>Large</i> )
Stretching	32	26	4.7 $\pm$ 0.5	3.4 $\pm$ 1.1*	1.57 $\pm$ 0.16 ( <i>Large</i> )
Cold baths	32	24	4.4 $\pm$ 0.7	4.0 $\pm$ 0.6	0.61 $\pm$ 0.06 ( <i>Moderate</i> )
Massages	32	24	4.2 $\pm$ 0.8	3.3 $\pm$ 0.9*	0.96 $\pm$ 0.10 ( <i>Moderate</i> )
Compression garment	32	11	4.0 $\pm$ 0.9	2.6 $\pm$ 0.8	1.52 $\pm$ 0.15 ( <i>Large</i> )
Contrast baths	31	21	3.9 $\pm$ 1.1	3.8 $\pm$ 0.9	0.15 $\pm$ 0.02 ( <i>Trivial</i> )
Pool recovery	32	21	4.3 $\pm$ 0.9	3.0 $\pm$ 0.9*	1.40 $\pm$ 0.14 ( <i>Large</i> )
Additional Sleep	30	20	4.4 $\pm$ 0.8	3.5 $\pm$ 1.1*	0.99 $\pm$ 0.10 ( <i>Moderate</i> )
PPDC	30	6	4.1 $\pm$ 0.6	3.2 $\pm$ 0.7*	1.38 $\pm$ 0.14 ( <i>Large</i> )
Hot baths	27	22	3.1 $\pm$ 1.0	2.9 $\pm$ 1.0	0.16 $\pm$ 0.02 ( <i>Trivial</i> )
Sauna	22	9	2.1 $\pm$ 1.0	2.6 $\pm$ 1.5	-0.39 $\pm$ 0.04 ( <i>Small</i> )
Electromyostimulation	3	3	I/N	I/N	
Cryotherapy	2	0	I/N	I/N	
NSAID	1	1	I/N	I/N	
Hyperbaric Oxygen Therapy	0	0	I/N	I/N	
<b>Importance of recovery:</b>			5.0 $\pm$ 0.2	4.9 $\pm$ 0.3	

\* Nonsteroidal Anti-Inflammatory Drugs (NSAID); Peristaltic pulse dynamic compression (PPDC); Insufficient number as less than 20% are familiar with that modality (I/N).

In comparison to the amateur group, athletes from the elite group implemented significantly more different recovery modalities per week ( $\sim 3$  vs  $\sim 8$ , respectively, Table 4). When comparing the total number of times per week athletes used recovery modalities, elite players used significantly more modalities ( $24.3 \pm 5.4$ ) than amateur

players ( $5.9 \pm 4.3$ , Table 4). The number of athletes that used cold baths, active recovery, massage, contrast baths, compression garments, pool recovery, additional sleep, stretching and PPDC were significantly greater in elite athletes when compared to amateur athletes (Table 4). In contrast, amateur athletes used hot baths significantly more than elite athletes for recovery (Table 4). No athletes in either group (elite and amateur) reported routine use of saunas, electromyostimulation, cryotherapy or hyperbaric oxygen therapy. No significant differences were found for the perceived effectiveness of massage ( $p > 0.05$ ). The correlations between the total number of times each recovery modality was implemented (i.e. number of athletes using multiplied by the average number of times each modality was used) and the perceived effectiveness of each recovery modality were found to be strong in the elite group ( $r = 0.70$ ) and moderate negative ( $r = -0.34$ ) in the amateur group.

**Table 4.** Relative values and differences (%) for the number of athletes that implemented each recovery modality. Mean  $\pm$  SD for the number of times each modality is used. \* Represents significant differences ( $p < 0.05$ ) between groups. Between-groups differences for the number of times each modality was implemented by week were only tested for modalities with over 20% users in each group.

Recovery modality:	Number of athletes implementing each recovery modality (%)			Number of times per week	
	Elite	Amateur	Diff.	Elite	Amateur
Cold baths	91%	54%	37%*	2.9 $\pm$ 0.9	1.08 $\pm$ 0.27*
Active recovery	94%	50%	44%*	2.6 $\pm$ 1.3	1.77 $\pm$ 1.19*
Hot baths	16%	38%	-23%*	1.8 $\pm$ 0.7 (I/N)	2.60 $\pm$ 0.92
Massages	91%	23%	68%*	1.4 $\pm$ 0.7	1.0 $\pm$ 0.0
Contrast baths	59%	15%	44%*	1.97 $\pm$ 0.8	2.00 $\pm$ 0.7 (I/N)
Compression garment	97%	8%	89%*	4.2 $\pm$ 2.2	2.50 $\pm$ 1.5 (I/N)
Sauna	0%	0%	0%	-	-
Pool recovery	91%	4%	87%*	2.8 $\pm$ 1.8	1.0 $\pm$ 0.0 (I/N)
Cryotherapy	0%	0%	0%	-	-
Electromyostimulation	0%	0%	0%	-	-
Additional Sleep	66%	31%	35%*	4.2 $\pm$ 2.2	2.4 $\pm$ 1.3*
NSAID	3%	0%	3%	1.0 $\pm$ 0 (I/N)	-
Stretching	100%	77%	23%*	5.3 $\pm$ 1.8	2.4 $\pm$ 1.1*
Hyperbaric Oxygen Therapy	0%	0%	0%	-	-
PPDC	78%	0%	78%*	2.44 $\pm$ 1.9	-
<b>Recovery modalities/week</b>	<b>7.8 <math>\pm</math> 1.3</b>	<b>3.0 <math>\pm</math> 1.8*</b>			
<b>Total number of times/week:</b>				<b>24.3 <math>\pm</math> 5.3</b>	<b>5.8 <math>\pm</math> 4.2*</b>

\* Nonsteroidal Anti-Inflammatory Drugs (NSAID); Peristaltic pulse dynamic compression (PPDC); Recovery modalities/week = Average number of different recovery modalities used per player each week; Total number of time/week = Average number of recovery modalities used per player x number of times each recovery modality is implemented per week; Insufficient number as less than 20% are familiar with that modality (I/N).

## Discussion

The main findings from the current study are that elite rugby athletes use significantly more recovery modalities (~8 vs 3) and implement them more often during the week (~25 vs ~6 times per week) in comparison to amateur rugby athletes (Table 4). Nevertheless, no differences were found for the perception of the importance of recovery (Table 3). Given that amateur athletes understand recovery to be as important as elite athletes, but they do not implement as many modalities as elite athletes, one can presume that: 1) amateur athletes might not have access to such modalities; 2) amateur athletes do not understand the effect that specific recovery modalities may play in overall recovery, possibly due to less experience with some of those recovery modalities; or 3) the amateur athletes are not exposed to the same amount of training load and collisions and therefore do not feel the need to use the same recovery modalities. When interpreting the data from the effectiveness of each recovery modality, elite athletes perceived all recovery modalities to be more beneficial in comparison to amateur, except for the use of saunas (Table 3). Significant differences ( $p < 0.05$ ) were found for active recovery, massage, pool recovery, additional sleep, PPDC and stretching (Table 3). Also, a *large* effect size was found for active recovery, compression garments, pool recovery, stretching and PPDC favouring elite athletes and for sauna favouring amateur athletes (Table 3). Given this, the differences observed in the number of recovery modalities and the total number of times a recovery modality is used per week can be in part explained by differences in the perceived effectiveness of recovery modalities between elite and amateur athletes. Moreover, while elite athletes demonstrated a strong positive correlation ( $r = 0.70$ ) between the total number

of times each recovery modality was implemented (i.e. number of athletes using x average number of times each modality was used) and the perceived effectiveness, amateur only demonstrated a moderate negative correlation ( $r = -0.34$ ). These findings may justify the lack of access (e.g. equipment, time) to recovery modalities.

In our study, the perceived effectiveness of stretching, cold and active recovery were ranked as the first, second and third most effective recovery modalities for elite rugby athletes. These results are in agreement with the study by Van Wyk & Lambert [42], where the authors verified exactly the same ranking order in the usage of recovery modalities (stretching, cold and active recovery) by elite rugby athletes. In contrast, amateur athletes only perceived cold baths to be effective (i.e. effectiveness rating  $> 4$ ) for recovery. Rugby is known to elicit high levels of muscle damage associated to the high intensity intermittent efforts and collisions [18, 35,55,56]. Given that cold recovery modalities lead to a decrease in swelling and inflammation [77–79], it is understandable why cold modalities are the most implemented recovery modality in the elite rugby environment [42] and also in the rugby specific recovery literature [107].

The lower perceived effectiveness of recovery modalities reported by amateur athletes can be related to the remarkable differences in the training week between elite and amateur rugby athletes (Table 2; Elite total training time = 600-660 minutes per week, Amateur total training time = 355-385 minutes per week). When comparing the typical training week of the amateur and the elite group, one can observe the differences in the training density (i.e. number of sessions per week), volume (i.e. duration of each session and total weekly training volume) and intensity (i.e. of each session and overall weekly intensity). Moreover, different levels of muscle damage after a match can be

observed between amateur and elite rugby, as demonstrated by increased creatine kinase (CK) levels following a match (941 to 2194  $\mu\text{L}$  post elite rugby matches [18–20] and 375 to 1081  $\mu\text{L}$  post amateur rugby matches [7, 24, 55,70]). Given that peak serum CK values are lower at amateur level, it is expected that CK values will return to baseline faster in comparison with elite rugby. For example, McLellan et al [18] observed significant increases in CK 120 hours following an elite rugby match, while Suzuki et al [70] verified that CK values returned to baseline 48 hours post a collegiate match. For the aforementioned reasons, it is expected that amateur athletes demonstrate lower fatigue levels, both after a match and during the training week, and therefore do not perceive the different recovery modalities as effective as elite athletes. In addition, some modalities (i.e. cold modalities) may reduce the muscle blood flow, therefore resulting in a reduction on anabolic signalling pathways and ultimately decreasing muscle adaptation to training [88,91,92]. For this reason, when training load is lower (e.g. amateur athletes), allowing for athlete to recovery naturally, the usage of such modalities is questionable [107]. Furthermore, the different teams staff may have an influence on athlete's perception of different recovery modalities.

In conclusion, results from our study demonstrate that no differences were found for the perception of the importance of recovery between elite and amateur rugby athletes. However, amateur rugby athletes use less recovery modalities and perceive particular recovery modalities as less effective in comparison to elite rugby players. The differences in the usage and perceived effectiveness of recovery modalities between groups may be, in part, due to the training week load (volume, intensity and density) of the amateur group (as demonstrated in Table 2) being considerably less than that of

the elite group, or simply the lack of experience with particular recovery modalities in the amateur group.

## **CHAPTER FOUR (STUDY THREE)**

### **Short-term effect of training and competition on muscle soreness and neuromuscular performance in elite rugby athletes.**

**Tavares F, Healey P, Smith TB, Driller M.** Short-term effect of training and competition on muscle soreness and neuromuscular performance in elite rugby athletes. *Journal of Australian Strength and Conditioning.* 2018; 26(1):11-17.

Understanding the impact of rugby training and competition on different markers of fatigue is important to provide information on the management of training loads. Neuromuscular performance is normally assessed from a countermovement jump and it is expected to be decreased in response to training load. Perceived muscle soreness is frequently monitored from a single-question and research investigating muscle soreness from different muscle sites in team-sport athletes is limited to one study in Australian-rules football. Measuring muscle soreness from different muscle sites provides important information regarding the management of training loads and program design. **Studies Three and Four** aimed to understand the levels of neuromuscular fatigue and muscle soreness from training and competition in rugby. Understanding the soreness from different muscle-sites provided important information for the questionnaire that was implemented in the cold water immersion intervention study (**Study Five**).

**Summary**

Lower body soreness is more sensitive than upper body soreness to fatigue. One recovery day is enough for upper body soreness to return to baseline but not for lower body. Muscle soreness remains elevated for two days following a match.

## **Abstract**

**Background:** Muscle soreness is frequently utilized to monitor fatigue in athletes and is typically measured from a whole body perspective, however, recent research recommends measuring muscle soreness across specific muscle sites. Therefore, the goal of the present study was to measure muscle soreness from different muscle sites within a group of elite rugby union players. **Methods:** Nineteen elite rugby players were monitored for muscle soreness obtained from 9 different muscle sites during a 9-day in-season period using a 5-point Likert scale (1- no soreness, 5 – maximal soreness). In addition, 13 of the 19 athletes performed countermovement jumps (CMJ) as a measure of neuromuscular performance to monitor fatigue. **Results:** No significant differences were observed for CMJ across days. A significant increase in muscle soreness from Baseline was found for Days 2, 3, 8 and 9 for all lower body muscles, while changes in upper body muscle soreness from Baseline were only significant for Days 8 and 9. When the average of the upper body (UB) and lower body muscle sites (LB) was calculated, it was found that UB soreness was significantly lower in comparison to both the LB soreness (Days 2 and 3) and the average of whole body (WB) (Days 5, 6 and 7). **Conclusion:** Lower body soreness of different muscle sites was more sensitive to training load in comparison to upper body. While one recovery day seemed to be adequate for UB to return to Baseline, LB was still significantly elevated. Lower body and UB soreness scores remained significantly higher than Baseline for at least two days following a match. **Practical applications:** Monitoring muscle soreness, in particular from the lower body, seems to provide important information for strength and conditioning coaches.

## **Introduction**

The magnitude of training adaptations that occur are the result of the balance between the training/competition stimulus and recovery [32]. In elite and amateur rugby players, training sessions often occur for two or more consecutive days during an in-season week [6]. Therefore, fatigue levels may not return to baseline between training sessions which can lead to an excessive level of accumulated fatigue during the week or training phase, compromising recovery and inhibiting positive training adaptations [12]. A large number of tests have been suggested by sport scientists [52,53] and implemented by strength and conditioning coaches [41] to monitor fatigue levels. In rugby, Twist and Highton have grouped these tests into the following categories: neuromuscular and performance tests, perception of fatigue and well-being questionnaires, and blood and salivary markers [52,53]. The most commonly reported and practical tests are questionnaires on the perceived level of fatigue and neuromuscular tests [41].

Neuromuscular performance tests have been extensively used for monitoring fatigue in rugby. These tests include measurement of performance in short distance sprinting [24,25], jumping [9–11, 25, 30,31,106], ballistic push ups [10], isometric [7,106] and isokinetic strength [30]. Jump assessments, in particular the bodyweight countermovement jump (CMJ), are the most common neuromuscular tests to monitor fatigue in rugby. Besides the reliability of the CMJ being high, a limited number of jump attempts represent negligible fatigue levels, and therefore, can be used on daily basis. However, some care needs to be taken with heavy and powerful athletes land from a CMJ (e.g. reduce the landing forces) [110]. The CMJ has been recommended as it demonstrates the highest repeatability and capability to assess immediate and

prolonged fatigue-induced changes in comparison to a squat jump or a drop jump [111]. However, previous research have demonstrated that during stretch shortening cycle jumping actions such as the CMJ, individuals are able to maintain mechanical output (i.e. jumping height) under fatigue from changes on the biomechanical phases of the jumps [112]. A large number of variables can be measured when the jumping test is performed on a force platform [111,113]. In addition, contact mats [114], linear position transducers [115], accelerometers [116] and smartphones [117] have also been reported to be valid and reliable instruments to obtain different jumping parameters. Rugby studies that have used CMJ to monitor fatigue have observed changes in flight time, maximum height, peak power and/or peak force [9–11, 25, 30,31,106]. Moreover, changes in countermovement jump performance has been associated with changes in the locomotive characteristics during an Australian-rules football match [118,119].

With regard to questionnaires for monitoring different aspects of fatigue, muscle soreness has been identified as the most frequently used item [41]. Muscle soreness has been shown to link to measures of decreased performance in rugby athletes [8]. A detailed description of the possible factors that explain the relationship between muscle soreness and neuromuscular fatigue can be found in Clarkson and Newman [120]. Historically, muscle soreness has been determined from one question that addresses general levels of overall muscle soreness [8]. Although monitoring muscle soreness in specific body parts is commonly used in endurance sports, only very recently has this been reported in the literature for team sports (i.e. Australian-rules football) [121]. Given the importance of tracking muscle soreness for high performance sports [41] and the regular collisions in rugby practice and competition, it might be useful to monitor

a range of upper and lower body muscle group soreness measures in rugby athletes [121,122]. Moreover, muscle soreness information obtained from different sites (e.g. upper body and lower body), allows the coaches to adapt training (e.g. off-feet conditioning) when some potential risk is observed. In addition, obtaining muscle soreness from left and right sides may provide important clinical information on injury prevention and management. To the best of the authors' knowledge, the monitoring of site specific muscle soreness has not been previously investigated in rugby. Therefore, the aim of this study was to measure muscle soreness from different muscle sites during an in-season phase in elite rugby athletes. In addition, this data was compared to a measure of neuromuscular fatigue, the countermovement jump.

## **Methods**

### *Approach to the Problem*

In order to understand the efficacy of monitoring muscle soreness from different sites, a group of elite rugby athletes competing in super rugby during the international window period in the middle of the season was monitored. This international window is typically a period where only international representatives play matches, however during this period the study participants competed against a touring International Rugby Board (IRB) Tier 1 international rugby team. Different measures calculated from a comprehensive body soreness questionnaire and countermovement jump performance were compared over a period of seven days prior to the International match and two days post-match (Table 1).

**Table 1.** Training program during the period of the study. Resistance training, conditioning and technical-tactical duration (minutes), and qualitative intensity or type of training are described.

		Training period								
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
Morning		OF (90'; High)	Gym session (LBRT: 75'; SS); OF (60'; Moderate)	OF (90'; High)	Non-training day	Gym session (WB: 60'; P/SS); OF (60'; Light)			Non-training day	OF (60'; Light)
Afternoon		Gym session (UBRT: 75'; SS) OF (60'; Moderate)	Con (60'; High)	OF (75'; High)		OF (75'; High)	OF (60'; Moderate)	Match (80'; Intense)		Gym session (UBRT: 75'; SS) OF (60'; Moderate)

Upper body resistance training (UBRT); Lower body resistance training (LBRT); Whole body resistance training (WB); Strength type of session (SS); Power type of session (P); On-Field session (OF); Conditioning session (Con).

### *Subjects*

Nineteen male professional rugby athletes volunteered to participate in the current study. The Athletes were part of a team competing in super XVIII rugby competition, comprising professional teams from Argentina, Australia, Japan, New Zealand and South Africa. The mean ( $\pm$  standard deviation) for height, weight and age of the participants was  $1.87 \pm 0.08$  m,  $104.8 \pm 14.0$  kg and  $25.9 \pm 3.6$  intra-day. All athletes volunteered to take part in the present study. Written informed consent was obtained from each participant, and ethical approval was obtained from the Human Research Ethics Committee of the University of Waikato.

### *Procedures*

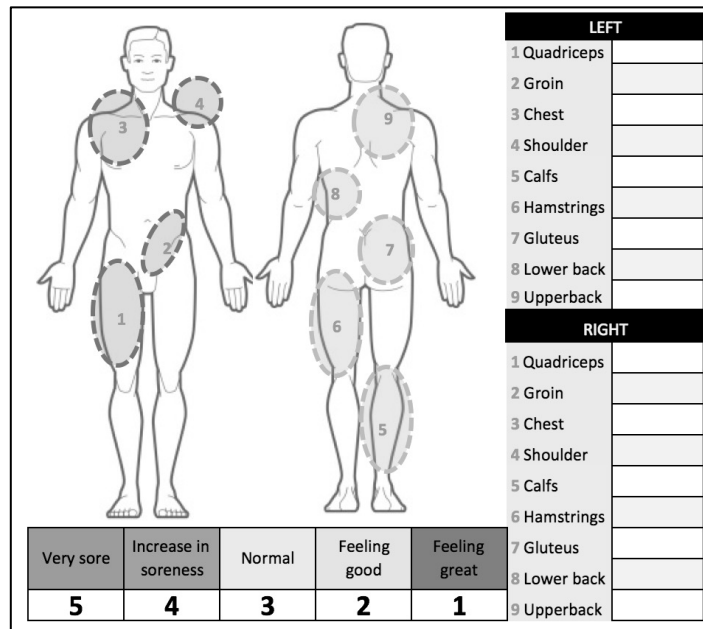
Morning measures of muscle soreness ( $n = 19$ ) and neuromuscular performance ( $n = 13$ ) were obtained on specific days during the nine-day period of the study. Jumps were

performed at the same time each day (~8:00 a.m.) to control for diurnal variation. Previous to the first day of data collection, athletes had performed a reduced-load training week without any matches. Moreover, no training was performed during the two days preceding the beginning of the study period. During the period of study the participant's undertook a program of various types, intensities and duration of exercise both on the rugby field and in the gym. All on-field rugby session loads (training and match) from all participants were monitored via global positioning system (GPS; Viper Pod, STATSport, Belfast, UK). Moreover, athletes were involved in recovery sessions that included the implementation of cold water immersion (i.e. after Days 5, 6 and 7), contrast water immersion (i.e. after Days 1 and 3) and the usage of compression garments during the night after every training and match day. In addition, athletes had a massage session at the end of Day 3 and a light 30-minute bike session on Day 4.

### *Perceptual measures*

The current study used a questionnaire based on the work of Montgomery and Hopkins [121]. In addition to the questions on lower body muscle sites that can be found in the Montgomery and Hopkins questionnaire [121], additional questions on upper body soreness were used (Figure 1). Moreover, the questionnaire contained soreness ratings from both left and right sides. A scale from 1-5 and athletes were instructed they could use 0.5-point increments to quantify the soreness level of nine different muscles/muscle sites from both sides of the body (Figure 1). Average from left and right sides for each muscle group were calculated in order to determine the difference for each variable between training days. A measure of lower body muscle soreness (LB) was calculated

from the sum of the left and right quadriceps, groin, calves, hamstrings and gluteus soreness. A measure of upper body soreness (UB) was calculated from the average of the left and right chest, shoulder, lower back and upper back muscle soreness. Finally, a measure of whole body soreness (WB) was calculated from the average of muscle soreness ratings from all muscles/muscle regions.



**Figure 1.** Body soreness graph questionnaire.

*Neuromuscular performance (Countermovement Jump Peak Force)*

In order to monitor neuromuscular fatigue, peak force (N) was measured on 13 athletes, during a countermovement jump (CMJ) test performed in the morning. Jumps were performed at the same time each day (~8:00 a.m.) to control for diurnal variation. Following a warmup composed of dynamic stretches and movements (e.g. one-leg standing knee flexion, bodyweight squats, bodyweight CMJ), subjects performed three CMJ with 15 seconds between each trial. Two force plates (PS 2142 Roseville, CA, USA) were used to measure peak force at a sample rate of 200 Hz. The force plates

were connected to an analog-to-digital converter (SPARKlink), which was then connected to a PC and the Pasco Capstone v1.4.0 software (PASCO, Roseville, California, USA) through a USB port. Each trial started with the subjects standing on the top of the force plates with their knees fully extended and their hands on hips to eliminate the influence of arm swing [113]. Subjects were then instructed to descend to a self-selected countermovement depth and to jump as high and quickly as possible [123]. The best trial, determined by peak force, was retained for later analysis using a customized software (WeightRoom, High Performance Sport New Zealand-Goldmine, Auckland, New Zealand). Peak force was selected as our findings from **Study Three** demonstrated that peak force obtained from the same setup and using a similar sample (elite rugby athletes) was reliable (between day ICC: 0.89; TE: 117.6 N; CV: 4.56%).

#### *Training load*

Locomotor activity of each participant was monitored during all technical-tactical training sessions with a 10 Hz GPS unit (Viper Pod, STATSport, Belfast, UK) incorporated into the players-jersey on the upper thoracic spine between the scapulae. In order to decrease the between-unit variability, the same GPS unit was used by each participant for every training session [124]. The GPS units were turned on before the warm-up and turned off after the completion of the training sessions. After each training session, the raw data files were analyzed and individual sessions' distance and high metabolic load distance (HML; distance covered  $> 5.5$  m/s and/or distance accelerating and decelerating over  $2$  m/s<sup>2</sup>) were obtained from the company's software (Viper PSA software, STATSports, Belfast, UK).

#### *Statistical Analyses*

The data collected was analyzed using a Statistical Package for Social Sciences (Version 22.0, SPSS Inc., IBM, Chicago). The Shapiro-Wilk test was performed to check the condition of normality for each variable. An ANOVA for repeated measures or a Friedman test (normality not observed or values on an ordinal scale) was used to analyze differences between and within training days for each variable. In order to compare the differences between left and right sides for soreness of the different muscles sites a Wilcoxon test was used. In order to compare differences between soreness variables and neuromuscular performance, the raw data of CMJ, LB soreness, UB soreness and WB soreness for each participant was converted to changes from Baseline (day 1 measures). A significance level of  $p < 0.05$  was implemented for all statistical tests.

## **Results**

Significant differences ( $p < 0.05$ ) were found between left and right sides for calf, hamstring and upper back muscles on Day 1. No other significant differences were found for differences in left and right sides for any muscles / muscle sites throughout the rest of the study period.

**Table 2.** Mean  $\pm$  SD soreness for the different muscles/muscle regions, wellness questionnaire parameters and CMJ performance (peak force, N).

	Day 1		Day 2		Day 3		Day 5		Day 6		Day 7 (match)		Day 8		Day 9	
	Mean	$\pm$ SD	Mean	$\pm$ SD	Mean	$\pm$ SD	Mean	$\pm$ SD	Mean	$\pm$ SD	Mean	$\pm$ SD	Mean	$\pm$ SD	Mean	$\pm$ SD
CMJ	<b>3054.1</b>	545.9	<b>2870.1</b>	442.9	<b>2829.3</b>	407.0	<b>2874.9</b>	440.8	<b>2956.0</b>	483.2	<b>3105.7</b>	572.9	<b>2879.9</b>	475.3	<b>2847.1</b>	497.7
Quadriceps	<b>1.3</b>	0.5 <sup>abfg</sup>	<b>2.6</b>	1.1	<b>2.7</b>	1.0 <sup>g</sup>	<b>2.2</b>	1.0	<b>2.1</b>	0.8	<b>2.1</b>	0.8	<b>3.1</b>	1.1	<b>2.7</b>	1.0
Groin	<b>1.4</b>	0.5 <sup>abfg</sup>	<b>2.3</b>	1.1	<b>2.3</b>	1.0	<b>2.1</b>	0.8	<b>2.1</b>	0.6	<b>2.2</b>	0.7	<b>3.0</b>	1.0	<b>2.7</b>	0.8
Chest	<b>1.5</b>	0.6 <sup>f</sup>	<b>2.1</b>	1.0	<b>2.0</b>	0.8	<b>2.0</b>	0.8	<b>2.1</b>	0.8	<b>2.0</b>	0.7	<b>2.8</b>	1.1	<b>2.3</b>	0.9
Shoulder	<b>1.8</b>	0.9 <sup>fg</sup>	<b>2.5</b>	1.1 <sup>g</sup>	<b>2.5</b>	1.0	<b>2.4</b>	1.0	<b>2.6</b>	0.9	<b>2.3</b>	0.9 <sup>f</sup>	<b>3.3</b>	1.1	<b>2.9</b>	1.2
Calves	<b>1.6</b>	0.8 <sup>abfg</sup>	<b>2.8</b>	1.2 <sup>g</sup>	<b>2.8</b>	1.0	<b>2.3</b>	1.1 <sup>f</sup>	<b>2.3</b>	0.7 <sup>f</sup>	<b>2.2</b>	0.7 <sup>f</sup>	<b>3.6</b>	1.1	<b>3.0</b>	1.1
Hamstrings	<b>1.4</b>	0.5 <sup>abefg</sup>	<b>3.0</b>	1.3	<b>3.2</b>	0.9 <sup>g</sup>	<b>2.5</b>	0.9	<b>2.4</b>	0.8 <sup>f</sup>	<b>2.6</b>	0.8	<b>3.4</b>	1.1	<b>3.1</b>	0.9
Gluteus	<b>1.3</b>	0.4 <sup>abfg</sup>	<b>2.7</b>	1.2 <sup>g</sup>	<b>2.7</b>	0.9	<b>2.3</b>	0.9	<b>2.2</b>	0.7 <sup>f</sup>	<b>2.2</b>	0.8 <sup>f</sup>	<b>3.2</b>	1.0	<b>2.9</b>	1.0
Lower back	<b>1.6</b>	0.8 <sup>dfg</sup>	<b>2.4</b>	1.1	<b>2.4</b>	1.1 <sup>g</sup>	<b>2.3</b>	1.0	<b>2.8</b>	1.0	<b>2.4</b>	0.8	<b>3.1</b>	1.0	<b>2.8</b>	0.9
Upperback	<b>1.5</b>	0.6 <sup>bfg</sup>	<b>2.1</b>	1.0 <sup>g</sup>	<b>2.2</b>	0.9	<b>2.1</b>	0.8	<b>2.1</b>	0.8 <sup>f</sup>	<b>2.1</b>	0.8 <sup>f</sup>	<b>3.1</b>	1.0	<b>2.8</b>	0.9
Soreness LB	<b>1.4</b>	0.5 <sup>abcfg</sup>	<b>2.7</b>	1.2 <sup>bcd<sup>f</sup></sup>	<b>2.7</b>	1.0 <sup>cf</sup>	<b>2.3</b>	0.9 <sup>defg</sup>	<b>2.2</b>	0.7 <sup>efg</sup>	<b>2.3</b>	0.8 <sup>fg</sup>	<b>3.3</b>	1.1 <sup>g</sup>	<b>2.9</b>	1.0
Soreness UB	<b>1.6</b>	0.7 <sup>abdfg</sup>	<b>2.3</b>	1.0 <sup>df</sup>	<b>2.3</b>	0.9 <sup>cdefg</sup>	<b>2.2</b>	0.9 <sup>defg</sup>	<b>2.4</b>	0.9 <sup>f</sup>	<b>2.2</b>	0.8 <sup>fg</sup>	<b>3.1</b>	1.1 <sup>g</sup>	<b>2.7</b>	1.0
Soreness WB	<b>1.5</b>	0.6 <sup>abcdfg</sup>	<b>2.5</b>	1.1 <sup>bcefg</sup>	<b>2.5</b>	1.0 <sup>cdf</sup>	<b>2.3</b>	0.9 <sup>defg</sup>	<b>2.3</b>	0.8 <sup>efg</sup>	<b>2.2</b>	0.8 <sup>fg</sup>	<b>3.2</b>	1.1 <sup>g</sup>	<b>2.8</b>	1.0

<sup>a</sup> Significant differences ( $p < 0.05$ ) from day 2

<sup>b</sup> Significant differences ( $p < 0.05$ ) from day 3

<sup>c</sup> Significant differences ( $p < 0.05$ ) from day 5

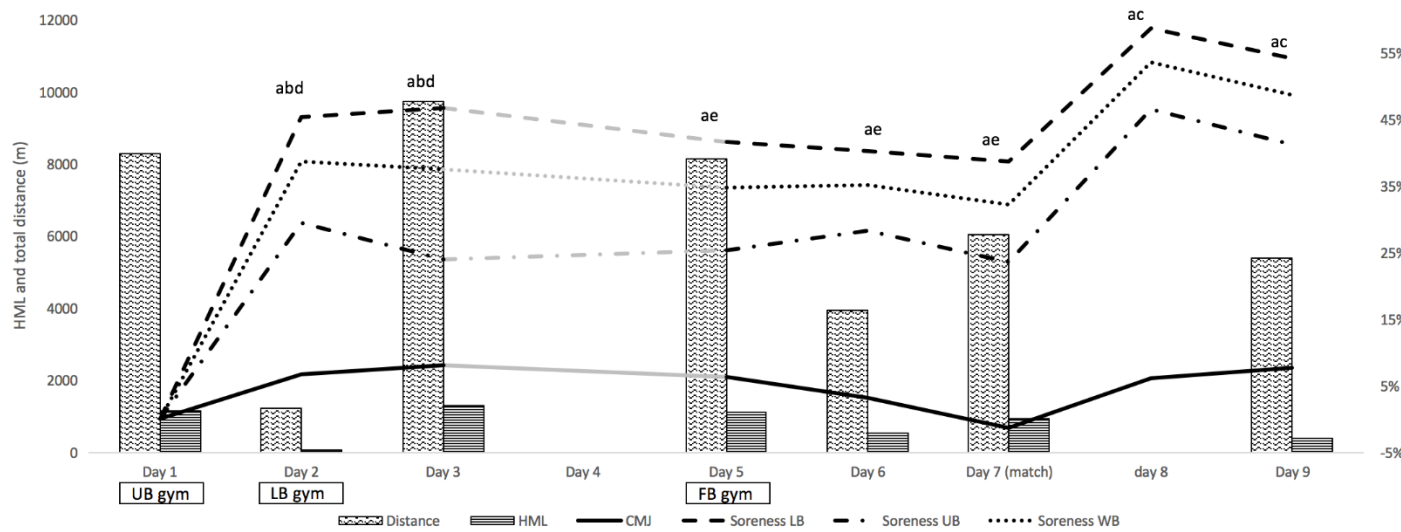
<sup>d</sup> Significant differences ( $p < 0.05$ ) from day 6

<sup>e</sup> Significant differences ( $p < 0.05$ ) from day 7

<sup>f</sup> Significant differences ( $p < 0.05$ ) from day 8

<sup>g</sup> Significant differences ( $p < 0.05$ ) from day 9

While no significant changes were observed between days for CMJ, significant changes were observed for various muscles / muscle sites (Figure 2 and Table 2). A significant increase in muscle soreness from Baseline (Day 1) was found for Days 2, 3, 8 and 9 for all lower body muscles, while changes in upper body muscle soreness from Baseline were only significant for Days 8 and 9. These differences in individual muscle / muscle sites led to significantly lower averages for UB soreness in comparison to LB and WB soreness. Although the same trend was observed between UB, LB and WB soreness (Figure 2), UB soreness was significantly lower compared to both WB (Days 5, 6 and 7) and LB (Days 2 and 3). Moreover, differences between CMJ and measures of soreness were observed in all training days.



**Figure 2.** Percentage changes from day 1 for CMJ peak force, WB soreness, LB soreness and UB soreness presented as lines and the units of measurement provided on the secondary intra-day-axis. Total distance (m) and HML distance (m) presented as bars and the units of measurement provided on the primary axis. a significant differences ( $p < 0.05$ ) between CMJ and WB soreness; b significant differences ( $p < 0.05$ ) between CMJ and LB soreness; c significant differences ( $p < 0.05$ ) between CMJ and UB soreness; d significant differences ( $p < 0.05$ ) between UB soreness and LB soreness; e significant differences ( $p < 0.05$ ) between UB soreness and WB soreness.

## **Discussion**

The present study aimed to compare different perceptual measures as a monitoring tool of physical recovery and readiness during a 9-day period in an elite group of rugby athletes. In addition, data from countermovement jump performance (N) was collected in a sub-sample (n = 13) throughout the study period. Based on the previous data collected with the team, the technical-tactical training load measured by both average of the individual athletes' distance (37,377 m from Day 1 to Day 7) and HML (5,090 m from Day 1 to Day 7) during the period of the study was considered very high. Data from rugby literature qualify distances  $\geq 28,798$  m over a seven day training period as a very high workload [125]. It is possible that the significant increases in the different measures of muscle soreness observed were due to the high running loads, but despite this, changes in neuromuscular performance were not evident (Table 2). While in this instance, elevated muscle soreness did not seem to induce a measurable increase in fatigue as determined by change in CMJ, further research with a greater sample size is recommended to confirm the findings of the current investigation. Moreover, investigation of other non-direct measures obtained from a CMJ performed on a force plate (e.g. jump height) should be explored.

Differences in soreness between days were more evident in lower body muscles / muscle sites when compared to upper body muscles. Significant increases on the days following the first training day and following the match day (Day 7) were observed. Moreover, when muscles were analysed separately, further increases in LB soreness,

but not in UB soreness, were observed from the first to the second training day, even when the running load was low. Nevertheless, when the UB muscles were merged, an increase in UB soreness from Day 1 to Day 2 was observed. The increases in UB soreness from Day 1 to Day 2 can be partially attributed to the upper body gym session on Day 1, while further increases in LB soreness from Day 2 to Day 3 were likely due to the lower body session that took place on Day 2. Although intensity (i.e. rate of perceived exertion) was not collected, the characteristics of the sessions (i.e. high loads quantified by GPS) are associated with muscle disruption [126,127] and consequently, muscle soreness [128].

When the athletes had a recovery day (Day 4), the muscle soreness tended to diminish. Nevertheless, the lower body muscle soreness scores remained above the Baseline. This data is not surprising, as increases in muscle soreness for up to four days have been previously reported in rugby athletes after a match [8]. Moreover, a cumulative effect on muscle soreness was still evident on the morning of the match. On the morning after the match, athletes reported the highest soreness scores for all muscles / muscle sites for the entire 9-day period.

Although the running load (total distance and HML) during the game was not higher in comparison to other training days (i.e. Days 1, 3 and 5), the high number of contacts that characterize a rugby match is known to lead to increases in muscle soreness [18, 31,55,56]. Increases in muscle soreness were still markedly high on the second morning after the match. Previous research demonstrating that increased levels of muscle soreness in elite rugby athletes are observed two to four days after a match support our

findings [8]. Practitioners should consider monitoring and managing training loads so athletes' soreness measures have returned to baseline prior to competition as muscle soreness may affect performance. However, it should be noted that in spite of the elevated pre-match soreness, CMJ was very similar to baseline, suggesting minimal neuromuscular fatigue.

When differences in left and right sides were compared, significant differences were only observed for calves, hamstrings and upper back before the first training day. Given that athletes came from a two-day period without training, such difference was not expected. However, a more prolonged increase in muscle soreness on one side can possibly be attributed to some minor injuries resulting from rugby practice in the previous week (e.g. contacts). Although differences in muscle soreness from left and right sides may not be a good indicator of training load, they can provide important information to the coaching and medical staff. For example, if an athlete presented with differences in muscle soreness between sides on Day 1 (e.g. differences greater than one point on the scale), and maintained the difference during the week, this might be indicative of uneven loading patterns, potentially leading to injury.

In conclusion, training and match load in an elite rugby squad elicited significant changes in muscle soreness, with changes being more pronounced in lower body muscles. No significant changes between days were observed for the CMJ despite significant increases in muscle soreness, but some caution must be taken when interpreting this data due to the sample size. Moreover, significant difference on Day 1 between left and right sides for certain muscles (i.e. calves and hamstrings) that play

an important role for jumping performance was observed. The differences in soreness between left and right sides on certain muscles can partially justify the lack of significant changes observed as the scores may not reflect a true baseline value. An important finding of this study was the fact that muscle soreness did not return to baseline prior to the match. Potentially the Day 5 training load (Table 1) was too high to allow athletes to fully recover. Strength and conditioning coaches and sport scientists involved in rugby should be aware of the effects of different types, intensities and duration of training on pre-match muscle soreness and how this may affect fatigue and subsequent performance. It would be interesting to explore the relationship between the typical scenario where a single question of muscle soreness is used [8], against the muscle soreness inventory employed in this study.

## **Practical applications**

Monitoring muscle soreness seems to provide important information for strength and conditioning coaches, and may provide further information that could help elucidate the fatigue state and/or recovery of their athletes. With this information, acute (e.g. when lower body soreness is reported to be very high, the strength and conditioning coach can substitute a running sprint session, where ground reaction forces are high [129], for a sprint session on a bike) and chronic (e.g. alteration of the order of the lower versus upper body gym sessions within the training week) changes in training sessions and weekly planning can be made. Moreover, obtaining data from left and right sides can add practical information for preventing and understanding injury mechanisms.

## **CHAPTER FOUR (STUDY FOUR)**

### **The effect of training load on neuromuscular performance, muscle soreness and wellness during an in-season non-competitive week in elite rugby athletes.**

**Tavares F**, Healey P, Smith TB, Driller M. The effect of training load on neuromuscular performance, muscle soreness and wellness during an in-season non-competitive week in elite rugby athletes. *The Journal of Sports Medicine and Physical Fitness*. 2018; Epub ahead of print. DOI: 10.23736/S0022-4707.17.07618-6

## **Abstract**

**Background:** In the elite rugby setting, it is critical to understand the effects of training load on the levels of fatigue, soreness and readiness of the athletes. **Methods:** The training load, wellness, neuromuscular markers of fatigue and various perceptual measures of soreness of 16 elite rugby athletes were monitored during a training week. Training load was obtained for field training sessions, extra conditioning and gym-based sessions. Perceptual fatigue was obtained every morning from a 5-item wellness questionnaire and a questionnaire on the muscle soreness of nine different muscle sites from each side of the body. Neuromuscular performance was obtained from a countermovement jump. **Results:** Although the training performed on Day 4 had a significantly ( $p < 0.05$ ) greater load in comparison to training Days 1 and 2, muscle soreness and neuromuscular performance were more adversely effected after the cumulative workloads of Days 1 and 2. Moreover, the effect of training load on muscle soreness was only evident in the lower body muscles. Data from the present study also suggest that two days off training are adequate for complete recovery from a high load training week in elite rugby athletes. There were no significant differences in soreness ratings between left and right sides for any of the nine muscles sites. **Conclusion:** There was a clear effect of training load on soreness and neuromuscular fatigue, with greater fatigue following two training days in a row when compared to a single training day. Monitoring soreness from different lower body muscle sites may provide important information that relates to the fatigue levels of rugby athletes and therefore it is recommended to be included as part of the training load monitoring protocol.

Keywords: Rugby - training load – fatigue – neuromuscular performance – muscle soreness

## **Introduction**

Rugby is an intermittent high-intensity team sport with bouts of high intensity (i.e. high speed runs, sprints, acceleration/decelerations and collisions) interspersed with low intensity activities or rest [1, 3,15,16]. At the elite level, rugby training often includes two or more sessions daily over two or more consecutive days during a training week [6, 8, 19,35]. Moreover, the combative contact and high-intensity intermittent nature of rugby can lead to notable muscle damage post-training and competition [18,19]. The short recovery times between training sessions in combination with the physical demands of rugby can lead to excessive levels of accumulated fatigue over the week cycle and result in undesirable fatigue states over a training phase [12] or under-performance on match day [10,11].

In order to monitor fatigue levels, support staff working with rugby have utilised a range of tests that include neuromuscular function, fatigue and well-being questionnaires, performance tests, and blood and salivary markers [52,53]. The most commonly used neuromuscular test in rugby is a countermovement jump [9]. A large number of variables can be measured when the jumping test is performed on a force platform [111,113], including changes in flight time, maximum height, peak power and/or peak force [9, 11,53]. With regard to the perception of fatigue and wellbeing, the questionnaire proposed by McLean et al. has been validated [8] and extensively used as a practical tool to monitor fatigue [53]. While most of the tests utilised in the research literature implement a lower body test to monitor fatigue, one study has assessed the effects of a rugby match on upper body fatigue [130]. The authors

observed differences between upper and lower body performance during an intensified week cycle with three collegiate rugby matches over a 5-day period. Amongst the different perceptual measures to monitor fatigue, muscle soreness has been identified as the most frequently used [41]. Moreover, muscle soreness has been shown to be related to decreased performance in rugby athletes [8]. The possible factors that explain the relationship between muscle soreness and neuromuscular fatigue are associated with structural damage in the skeletal muscle and consequent disorganisation of the myofilament alignment (see refs: [120,128]). Although monitoring muscle soreness in specific body parts is commonly used in endurance sports, this analysis has only recently been implemented in team sports (i.e. Australian-rules football) [121]. Given the importance of tracking muscle soreness for high performance sports and athletes [131], it might be useful to include measures of muscles soreness from different muscle groups as part of the overall wellness monitoring procedure [121,122]. Furthermore, given the high-collision nature of rugby training and competition, it may be advantageous to include information about muscle soreness in the upper body [130]. Moreover, if the soreness information is obtained independently for upper and lower body, it allows the coaches to adapt training (e.g. off-feet conditioning) when soreness ratings exceed levels that are deemed above the potential risk thresholds established by the team.

While much attention has been focused on the effect of rugby match-play on fatigue, less is known about how rugby training affects an athletes acute fatigue and readiness during a training week in highly-trained, professional rugby players [19, 63,75].

Nevertheless, this topic has gained attention in other sport modalities, including soccer [132–135] and basketball [136]. Understanding the acute effects of fatigue imposed by typical training periods allows support staff to have a better understanding of tolerance and stress caused by training. Moreover, although the usage of a different muscle site soreness questionnaire has been previously recommended [121,122], to our knowledge, only one study has implemented this monitoring tool in their protocols [121]. Therefore, the purpose of the current study was to analyse the acute effects of training load during an in-season, non-competition week in a professional rugby team, and to compare the responses of different perceptual and neuromuscular measures to overall training load.

## **Methods**

### *Participants*

Sixteen male professional rugby athletes volunteered to participate in the current study (Table 1). Athletes were members of a team competing in the super rugby competition, the major competition in the southern hemisphere comprising of teams from Argentina, Australia, Japan, New Zealand and South Africa. The super rugby competition is considered to be the highest level of rugby competition outside international fixtures for these nations. The super rugby season typically breaks for a period of four weeks where no competition games are played due to international fixtures taking place. This period provides a unique opportunity for teams to recover from accumulated fatigue and pursue gains in various physical qualities. Data from the first seven days during

this non-competitive period was collected. Written informed consent was obtained from each participant, and ethical approval was obtained from the Human Research Ethics Committee of the Institution.

**Table 1.** Participant demographics. Data shown as means  $\pm$  SD.

	Professional rugby athletes (n = 16)
Age (years)	25 $\pm$ 3
Body weight (kg)	102.5 $\pm$ 15.2
Height (cm)	185.6 $\pm$ 7.6
Total rugby experience (years)	15.2 $\pm$ 5.8
Professional rugby experience (years)	5.1 $\pm$ 3.7

### *Procedures*

The timetable of the team training schedule and the various measures performed during a 7-day, non-competitive microcycle are presented in Table 2. Measures of perceptual wellness and muscle soreness were collected every day and neuromuscular jump performance was collected on Days 1, 2, 3, 4, and 7 (Table 2). During this period, all training session loads from all participants were measured by either global positioning system (GPS; Viper Pod, STATSport, Belfast, UK) during the on-field sessions, or individual subjective rating of perceived exertion (RPE) for the off-field strength and/or conditioning sessions.

### *Perceptual measures*

The McLean and colleagues' wellness questionnaire [8] was completed by all

participants each morning during the period of the study. This questionnaire comprised of five questions and was designed to measure the perceived fatigue (fatigue WQ), general muscle soreness (soreness WQ), sleep quality, stress levels, and mood state of athletes using a 1-5 Likert scale with 0.5-point increments [8]. A total score (total WQ) for the questionnaire was calculated as the sum of the answers for the five items. In order to gain a more detailed understanding of muscle soreness, a second questionnaire based on the work of Montgomery and Hopkins [121] was also completed each morning. In addition to the questions on lower body muscle sites that can be found in the Montgomery and Hopkins questionnaire [121], additional questions on upper body soreness were (i.e. chest, shoulder, lower back) included (Figure 1). Moreover, soreness from the left and right sides of each of the muscle sites were collected. In order to be coherent with McLean and colleagues' questionnaire, a scale from 1-5 with 0.5-point increments was used to quantify the soreness level of 18 different muscle sites (nine from the left and the equivalent nine from right side, Figure 1). A measure of lower body muscle soreness (soreness LB) was calculated from the average of the left and right quadricep, groin, calf, hamstring and gluteus muscle soreness. A measure of upper body soreness (soreness UB) was calculated from the average of the left and right chest, shoulder, lower back and upper back muscle soreness. The whole-body soreness (soreness WB) was calculated from the sum of all muscles/muscle regions.

Very sore		Increase in soreness	Normal	Feeling good	Feeling great
5	4	3	2	1	

LEFT	
1	Quadriceps
2	Groin
3	Chest
4	Shoulder
5	Calfs
6	Hamstrings
7	Gluteus
8	Lower back
9	Upperback

RIGHT	
1	Quadriceps
2	Groin
3	Chest
4	Shoulder
5	Calfs
6	Hamstrings
7	Gluteus
8	Lower back
9	Upperback

**Figure 1.** Body soreness questionnaire.

*Neuromuscular performance (Countermovement Jump Peak Force)*

In order to monitor neuromuscular fatigue, peak force (N) was measured during a countermovement jump (CMJ) test performed each morning of the training week (Table 2). Following a standardized warm-up comprising of dynamic stretches and movements (e.g. one-leg standing knee flexion, bodyweight squats, bodyweight CMJs) athletes performed three CMJ with 15 second intervals between each jump. Two force plates (PASCO PS 2142, Roseville, CA, USA) were used to measure peak force at a sampling rate of 200 Hz. The force plates were connected to an analog-to-digital converter (SPARKlink), which was then connected to a PC and the Pasco Capstone v1.4.0 software (PASCO, Roseville, California, USA) through a USB port. Each trial started with the subjects standing on the top of the force plates with their knees fully extended and the hands on hips to eliminate the influence of arm swing [113]. Subjects

were then instructed to descend to a self-selected countermovement depth and to jump as high and quickly as possible [123]. The best trial, determined by peak force, was retained for later analysis using a customized software package (WeightRoom, High Performance Sport New Zealand-Goldmine, Auckland, New Zealand). Our unpublished data from 18 elite rugby athletes demonstrate that PF obtained with this setup has an acceptable level of test-retest reliability (ICC: 0.89; CV: 4.6%).

### *Training load*

Locomotor activity of each participant was monitored during all on-field training sessions with a 15Hz GPS unit (Viper Pod, STATSport, Belfast, UK) inserted into the players' jersey on the upper thoracic spine between the scapulae. In order to decrease the between-unit variability, the same GPS unit was used by each participant for subsequent sessions [124]. The GPS units were turned on before the warm-up and turned off after the completion of the training sessions. After each training session, the raw data files were analyzed and individual sessions' distance and high metabolic load distance (HML; distance covered  $> 5.5$  m/s and/or distance accelerating and decelerating  $> 2$  m/s<sup>2</sup>) were obtained from the company's software (Viper PSA software, STATSports, Belfast, UK). The individual training RPE of the off-field conditioning and gym training sessions were obtained between 15 and 30 minutes after the completion of the session [137,138]. The training load for these sessions was then calculated as the product of the individual session RPE (sRPE) and the duration of the session using the following formula: Training load = sRPE (1-10) x duration of the session (min) [122,137].

**Table 2.** Training program during the period of the study. Resistance training, conditioning and technical-tactical duration (minutes), and qualitative intensity or type of training described. Data from technical-tactical training (distance, high metabolic load, resistance training and extra-conditioning (arbitrary units: sRPE x duration) are represented as mean  $\pm$  SD. All fatigue monitoring data collection occurred before the first session of the day.

	Training period						
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Before	J+Q+S	J+Q+S	J+Q+S	J+Q+S	Q+S	Q+S	J+Q+S
Morning	<b>Gym session</b> (WB: 72.5'; SS); <b>OF</b> (45'; Moderate)	<b>Gym session</b> (WB: 74'; P); <b>OF</b> (45'; Moderate)	Theory sessions	<b>Gym session</b> (WB: 70'; P); <b>OF</b> (75'; Light/Moderate)	Day-off	Day-off	
Afternoon	<b>OF</b> (75'; High)	<b>OF</b> (90'; High); <b>Con</b> (44'; High)		<b>OF</b> (75'; High)			
Conditioning (AU)		375 $\pm$ 40					
Weights (AU)	442 $\pm$ 110	446 $\pm$ 94		336 $\pm$ 70			
TT distance (m)	7154 $\pm$ 1569	7059 $\pm$ 1215		9308 $\pm$ 629			
TT HML	982 $\pm$ 335	1057 $\pm$ 322		1392 $\pm$ 244			

Jumping performance (J); Wellness questionnaire (Q); Soreness questionnaire (S); Whole body resistance training (WB); Strength type of session (SS); Power type of session (P); On-Field session (OF); Conditioning session (Con); Arbitrary units (AU); High metabolic load (HML).

### *Statistical Analysis*

The data collected was analyzed using a Statistical Package for Social Sciences (Version 22.0, SPSS Inc., IBM, Chicago, IL, USA). The Shapiro-Wilk test was performed to assess normality for each variable. An ANOVA for repeated measures was used to analyze differences between training days and Baseline (Day 1). Whenever the condition of normality of a variable was rejected or the values were presented on an ordinal scale (wellness and body soreness questionnaires) a Friedman test was utilized. A Wilcoxon test was used to compare the differences between left and right

sides for soreness of the different muscles sites. A significance level of  $p < 0.05$  was implemented for all statistical tests.

In addition, the standardised change in the mean for CMJ, total soreness (WB, UB and LB) and the wellness questionnaire compared to Baseline for each day was determined and expressed as effect sizes (Cohen's  $d$ ) by dividing by the average Baseline between-subject SD for that variable. Magnitudes of the standardised effects for CMJ and total scores of soreness were interpreted using thresholds of 0.2, 0.6 and 1.2 for *small*, *moderate* and *large*, respectively [139]. For the ordinal variables, the equivalent effect sizes were 0.1, 0.3 and 0.5 of the range of 4 for the 5-point Likert scale, which equates to thresholds of 0.4, 1.2 and 2.0 for *small*, *moderate* and *large*, respectively [140]. An effect size of  $< 0.2$ , or  $< 0.4$  for the 5-point Likert scale was considered *trivial* [139,140]. Where the 90% confidence limits overlapped *small* positive and negative values, the effect was deemed *unclear*.

## **Results**

Strength training sRPE for Day 1 and 2 were significantly ( $p < 0.05$ ) greater in comparison to Day 4. In contrast, technical-tactical training load (total distance, HML) was significantly lower ( $p < 0.05$ ) on Day 1 and 2 in comparison to Day 4 (Table 2). Moreover, based on our previous data, the on-field training load measured by both distance and HML during the period of the study was considered high. Previous rugby literature have categorized weekly running distances between 22,365 and 28,797 m as high workloads as high [125].

No differences ( $p < 0.05$ ) were found between left and right sides for any of the muscle sites over the duration of the study. Therefore, the analysis of soreness at differences in muscle sites compared to Baseline were made for merged data between left and right sides (average of both sides taken).

Significant differences ( $p < 0.05$ ) were found between Day 2 and Day 3 in comparison to Baseline for neuromuscular fatigue and muscle soreness (Table 3). No significant differences to Baseline were found for any other training day. In addition, no significant differences to Baseline for any upper body muscle sites or for any item of the wellness questionnaire (except muscle soreness) were observed during the training week.

**Table 3.** Mean  $\pm$  SD soreness for the muscles/muscle regions, wellness questionnaire parameters and CMJ performance (peak force).

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	
CMJ (N)	2774 $\pm$ 431	2678 $\pm$ 393	2646 $\pm$ 315*	2690 $\pm$ 400			2708 $\pm$ 352	
Muscle soreness	Quadriceps	2.3 $\pm$ 0.8	2.9 $\pm$ 0.7	3.2 $\pm$ 0.9*	2.6 $\pm$ 0.9	2.7 $\pm$ 1.0	2.3 $\pm$ 0.7	2.2 $\pm$ 0.7
	Groin	2.4 $\pm$ 0.7	2.8 $\pm$ 1.0	3.0 $\pm$ 0.9*	2.5 $\pm$ 0.9	2.6 $\pm$ 0.8	2.3 $\pm$ 0.8	2.2 $\pm$ 0.8
	Chest	2.1 $\pm$ 0.8	2.6 $\pm$ 0.8	2.6 $\pm$ 0.8	2.5 $\pm$ 0.8	2.4 $\pm$ 0.7	2.1 $\pm$ 0.6	2.0 $\pm$ 0.8
	Shoulder	2.5 $\pm$ 0.9	2.7 $\pm$ 0.9	3.0 $\pm$ 0.8	2.6 $\pm$ 0.8	2.7 $\pm$ 0.9	2.6 $\pm$ 0.8	2.3 $\pm$ 0.9
	Calves	2.3 $\pm$ 0.9	2.9 $\pm$ 0.7	3.2 $\pm$ 0.8*	2.8 $\pm$ 1.0	2.9 $\pm$ 0.9	2.5 $\pm$ 0.7	2.6 $\pm$ 0.8
	Hamstrings	2.4 $\pm$ 0.9	3.3 $\pm$ 0.8*	3.5 $\pm$ 0.8*	3.1 $\pm$ 1.0	3.1 $\pm$ 0.8	2.6 $\pm$ 0.6	2.6 $\pm$ 0.9
	Gluteus	2.5 $\pm$ 0.9	2.9 $\pm$ 1.1	3.2 $\pm$ 1.0*	2.7 $\pm$ 0.8	2.7 $\pm$ 1.0	2.4 $\pm$ 0.8	2.3 $\pm$ 0.7
	Lower Back	2.7 $\pm$ 0.9	3.1 $\pm$ 1.0	3.3 $\pm$ 0.6	2.8 $\pm$ 0.9	3.0 $\pm$ 1.1	2.8 $\pm$ 0.9	2.7 $\pm$ 0.7
	Upper Back	2.2 $\pm$ 0.8	2.4 $\pm$ 0.8	2.6 $\pm$ 0.9	2.4 $\pm$ 0.9	2.6 $\pm$ 0.8	2.2 $\pm$ 0.7	2.2 $\pm$ 0.8
	Upper body	2.4 $\pm$ 0.6	2.7 $\pm$ 0.6	2.9 $\pm$ 0.6	2.6 $\pm$ 0.7	2.7 $\pm$ 0.7	2.4 $\pm$ 0.6	2.3 $\pm$ 0.6
	Lower Body	2.4 $\pm$ 0.8	3.0 $\pm$ 0.9*	3.2 $\pm$ 0.9*	2.7 $\pm$ 0.9	2.8 $\pm$ 0.9	2.4 $\pm$ 0.7	2.4 $\pm$ 0.8
	Whole Body	2.4 $\pm$ 0.8	2.8 $\pm$ 0.9*	3.0 $\pm$ 0.9*	2.7 $\pm$ 0.9	2.7 $\pm$ 0.9	2.4 $\pm$ 0.7	2.3 $\pm$ 0.8
Wellness Questionnaire	Fatigue	2.4 $\pm$ 0.8	2.8 $\pm$ 0.6	3.2 $\pm$ 0.7	2.6 $\pm$ 0.7	3.0 $\pm$ 0.7	2.3 $\pm$ 0.9	2.1 $\pm$ 0.9
	Sleep	2.1 $\pm$ 0.8	2.3 $\pm$ 0.7	2.2 $\pm$ 0.8	2.4 $\pm$ 0.6	2.1 $\pm$ 0.6	1.8 $\pm$ 1.0	2.3 $\pm$ 0.9
	Soreness	2.4 $\pm$ 0.8	3.2 $\pm$ 0.8	3.6 $\pm$ 0.6*	2.8 $\pm$ 0.8	3.2 $\pm$ 0.8	2.4 $\pm$ 0.7	2.1 $\pm$ 1.0
	Stress	2.3 $\pm$ 0.8	2.5 $\pm$ 0.6	2.3 $\pm$ 0.6	2.3 $\pm$ 0.6	2.2 $\pm$ 0.8	1.8 $\pm$ 0.8	1.8 $\pm$ 0.7
	Mood	2.1 $\pm$ 0.7	2.1 $\pm$ 0.4	2.1 $\pm$ 0.6	2.3 $\pm$ 0.6	1.9 $\pm$ 0.6	1.7 $\pm$ 0.7	1.8 $\pm$ 0.7
	Total	11.2 $\pm$ 3.2	12.8 $\pm$ 2.0	13.3 $\pm$ 2.2	12.5 $\pm$ 2.3	12.4 $\pm$ 2.4	10.5 $\pm$ 2.4	10.1 $\pm$ 3.5

\*Significant difference ( $p < 0.05$ ) from Baseline (Day 1).

In addition, *small* effects were found between Baseline and both Day 2 ( $d = 0.21$ ) and Day 3 ( $d = 0.28$ ) for CMJ. *Small* and *moderate* effects were found for fatigue, soreness, sleep and total items of WQ. For fatigue WQ, a *small* ES was found between Baseline and both Day 3 ( $d = 0.87$ ) and Day 5 ( $d = -0.66$ ). For soreness WQ, a *moderate* ES was

found between Baseline and Day 3 ( $d = 1.40$ ) and a *small* ES was found between Baseline and Day 2 ( $d = 0.96$ ), Day 4 ( $d = 0.55$ ) and Day 5 ( $d = 0.96$ ). For sleep, a *small* ES was found between Baseline and both Day 4 ( $d = 0.43$ ) and Day 7 ( $d = 0.46$ ). For the total of the WQ items a *moderate* ES was found between Baseline and Day 3 ( $d = 0.64$ ) and a *small* ES was found between Baseline and Days 2 ( $d = 0.47$ ), 4 ( $d = 0.40$ ) and 5 ( $d = 0.37$ ). For the soreness calculated from WB, *small* effects were observed for Days 4 ( $d = 0.43$ ) and 5 ( $d = 0.53$ ) in comparison to Baseline. Also for soreness WB, a *moderate* ES was observed for Days 2 ( $d = 0.67$ ) and 3 ( $d = 0.98$ ) in comparison to Baseline. For soreness UB, a *small* ES was observed for Days 2 ( $d=0.47$ ) and 5 ( $d=0.44$ ), and a *moderate* ES was observed for Day 3 ( $d = 0.71$ ) in comparison to Baseline. Finally, for total LB soreness, a *small* ES was observed for Day 4 ( $d = 0.51$ ) and Day 5 ( $d = 0.57$ ) in comparison to Baseline, and *moderate* effects were observed for Day 2 ( $d = 0.78$ ) and Day 3 ( $d = 1.12$ ) in comparison to Baseline.

## **Discussion**

The effect of training load on the increase in muscle soreness and decrease in neuromuscular performance was evident. This was demonstrated by a significant increase in lower body soreness and neuromuscular fatigue on Days 2 and 3 (Table 3). In addition, there was a cumulative effect of training load on fatigue measures, as there were a greater number of soreness items and CMJ demonstrating significant changes between Day 3 and Baseline in comparison to Day 2 and Baseline (Table 3). The more pronounced changes in muscle soreness and neuromuscular performance after two days of training can be explained by the incomplete period of rest between training days

[32].

Given that the Day 4 total technical-tactical load (i.e. time, distance, HML) was significantly greater in comparison to the Day 1, one could expect that significant changes would be observed in some parameters on the day after. However, the perceived exertion for the gym based resistance and conditioning sessions on Day 1 and 2 was significantly greater in comparison to Day 4 (Table 2). Furthermore, on Day 1 athletes were exposed to high strength training loads in the gymnasium (e.g. 1-5 RM; 88-100% 1-RM) while on Day 2 athletes trained with moderate-loads and moderate-velocity (e.g. 60-70% 1-RM) and Day 4 with low loads and high velocity (e.g. 0-30% 1-RM). Higher strength training load (e.g. > 60% 1-RM) is associated with a greater muscle disruption [126,127] and consequently, higher levels of muscle soreness [128]. These results demonstrate that athletes were not fully recovered on either Day 2, 3 or 5 during the training week.

An important finding of the present study is the demonstration of a cumulative effect of training load on fatigue, and the return to baseline after two rest days (i.e. no significant differences and *trivial* effect sizes for Days 6 or 7 in comparison to Baseline). Understanding the effects of training load patterns is important to avoid undesirable states of fatigue [12]. Our findings demonstrated that lower body muscle sites were more sensitive to training load with no significant changes to Baseline being observed in individual upper body sites or the average of UB sites (soreness UB). Nevertheless, *small* and *moderate* effects were observed for soreness UB. Previous research has observed the effects of rugby training on upper body neuromuscular

performance following small sided games [130]. Using the muscle soreness from different lower body muscle sites appears to be more sensitive than a single question on muscles soreness (soreness WQ) and CMJ performance, as these measures were only different on Day 3 in comparison to Baseline. In addition, *moderate* effect sizes were observed between Day 2 and Baseline for soreness WB and soreness LB while only *small* effects were observed for soreness WQ and CMJ. For this reason, measuring the soreness from different lower body muscle sites may provide better information for monitoring fatigue levels. The differences observed on muscle soreness for different muscle sites support previous research in team sports [121] on the efficacy of only measuring lower body soreness rather than whole body soreness.

A questionnaire designed to obtain soreness from different lower body muscle sites seems to provide adequate information on the recovery status of athletes. No significant differences were found when muscle soreness from different muscle/muscle regions were compared between left and right sides of the body. However, collecting muscle soreness data from left and right sides may provide important information for medical and coaching staff (i.e. individual differences between sides) and therefore should be collected [122]. For example, if an athlete presented with differences in muscle soreness between sides on day one, and maintained the difference during the week, this might be indicative of uneven loading patterns, potentially leading to injury.

In conclusion, training load in an elite rugby squad elicits significant changes in physiological and perceptual measures of fatigue and soreness, particularly when the recovery period between training days was reduced. There was a cumulative effect of

fatigue over the training week, with two days of rest being sufficient to fully return all measures of fatigue and soreness to the baseline values. The measures of muscle soreness show similar changes to measures of fatigue, with the sum of various lower body muscle sites being more sensitive than a single question about soreness. Monitoring muscle soreness from specific lower body sites seems to provide important information for coaches, and may provide further information that could help elucidate the fatigue state and/or recovery of their athletes. Therefore, we would recommend it to be included as part of the fatigue monitoring protocol used by medical and coaching staff.

## CHAPTER FIVE

### **The effects of chronic cold water immersion in elite rugby players**

**Tavares F**, Beaven M, Teles J, Baker D, Healey P, Smith TB, Driller M. The effects of chronic cold water immersion in elite rugby players. *International Journal of Sports Physiology and Performance*. 2018; Epub ahead of print. DOI: 10.1123/ijsp.2018-0313

While the acute effects of cold water immersion (i.e. up to 48 h post-exercise) have been extensively described in literature, studies analyzing the chronic use of cold water immersion are scarce and limited to athletes exposed to low density weekly training schedules or endurance athletes. Adaptations from training result from a balance between training loads and recovery, therefore when athletes are exposed to high training loads and have limited time to recover, fatigue can accumulate and interfere with responses to training; i.e. athletes may not be able to sustain a desirable training load. Moreover, if high training loads are sustained for long periods of time, it may lead to maladaptive adaptation phases (e.g. over-training). **Study Five** aimed to understand the effects of regular cold water immersion exposure on recovery and adaptation during an intense three-week training phase in elite rugby players.

## Abstract

**Purpose:** While the acute effects of cold water immersion (CWI) have been widely investigated, research analysing the effects of CWI over a chronic period in highly-trained athletes is scarce. The aim of this study was to investigate the effects of CWI during an intense three week pre-season phase in elite rugby athletes. **Methods:** Twenty-three elite male rugby union athletes were randomized to either CWI (10 min at 10 °C, n = 10) or a passive recovery control (CON, n = 13) during three-weeks of high volume training. Athletes were exposed to either CWI or CON, after each training day (12 days in total). Running loads, conditioning and gym sessions were kept the same between groups. Measures of countermovement jump (CMJ), perceived muscle soreness and wellness were obtained twice a week, and saliva samples for determining cortisol and interleukin-6 (IL-6) were collected once per week. **Results:** Although no significant differences were observed between CWI and CON for any measure, CWI resulted in lower fatigue markers throughout the study, as demonstrated by the *moderate* effects on muscle soreness ( $d = 0.58$  to  $0.91$ ) and IL-6 ( $d = -0.83$ ), and the *small* effects ( $d = 0.23$  to  $0.38$ ) on CMJ in comparison to CON. **Conclusions:** The results from this study demonstrate that CWI may provide some beneficial effect by reducing fatigue and soreness during an intense three week training phase in elite rugby athletes.

Keywords: Recovery, fatigue, chronic, acute, adaptation

## **Introduction**

At the elite level, rugby training often occurs two or more times daily over two or more consecutive days during a week [107,141]. An imbalance between training stress and recovery can lead to an excessive level of accumulated fatigue over the training week [141] and undesirable chronic fatigue over a training phase [12]. Increased fatigue over time can lead to the athlete being unable to train at a required intensity or being unable to perform the desired training load [37]. In order to reduce the harmful effect of fatigue and allow athletes to recover faster, athletes regularly implement different recovery modalities in their routines [107,141,142].

Previous literature has identified cold-water modalities as one of the most common recovery strategies implemented by elite rugby athletes [107,141]. The exposure to cold water decreases skin, core and muscle temperature [143], leading to vasoconstriction, and consequently, it may decrease swelling and acute inflammation from muscle damage [79]. Furthermore, the use of cold water immersion (CWI) contributes to a reduction in nerve conduction properties and to a decrease in muscle spasm and pain [79]. CWI in an acute rugby setting (< 48 h post-exercise) has been effective in increasing neuromuscular function [9,21], enhancing perceived recovery [21], and decreasing both delayed onset muscle soreness (DOMS) [9] and creatine kinase levels [9].

Given the beneficial effects of CWI in enhancing recovery in rugby, this modality has become commonplace following both matches and training sessions [83,107].

However, some researchers argue that the use of CWI post-exercise in a chronic setting may blunt adaptations by reducing muscle protein synthesis and therefore limiting muscle mass maintenance/growth [88]. Mechanisms involved in the hypertrophy of the muscle cell are thought to be partially associated with exercise-induced muscle damage (EIMD) and the consequent increases in the activity of satellite cells and inflammatory cells as well as the increase in the cell swelling [88]. These responses to EIMD are proposed to mediate various anabolic signalling pathways that ultimately increase the rates of protein synthesis [88]. Roberts et al. [88] observed an acute decrease in the activity of selected components of the mammalian target of rapamycin pathway and satellite cells after 10 minutes of CWI at ~10 °C performed post-resistance training. In the same study, the authors observed that CWI attenuated muscle mass (but not type II fibre cross sectional area or myonuclear accretion) after 12 weeks of lower body resistance training composed of two sessions per week [88].

Interestingly though, when the recovery time was shorter (i.e. 6 h) the same authors report that CWI enhances recovery of muscle function and allows athletes to complete more work during subsequent training sessions [144]. Furthermore, during an intensified training phase for elite cyclists, Halson et al. [142] found likely beneficial effects of CWI in the mean power of a four minute cycling test and the one second maximum power in a sprint test. In this study the elite cyclists trained on a daily basis, therefore, the time for recovery was shorter than the typical studies investigating the effects of CWI on performance [142]. Together, these findings demonstrate that when recovery time is limited, CWI may provide a beneficial acute effect on performance

that will reflect the chronic adaptations to a training regime. Research on the effects of chronic exposure to CWI (i.e. during consecutive training weeks) on rugby players, is limited to a single study performed on age-group athletes, which found no differences in performance, DOMS and perceived recovery [27]. Based on the aforementioned findings, two theories have been proposed for the response to CWI: 1) These modalities allow athletes to perform subsequent training sessions with a greater quality and/or quantity (i.e. greater training load); or 2) These modalities may blunt selected muscular adaptations to training (i.e. decrease protein synthesis) [142].

To the best of our knowledge, research investigating the training responses in elite athletes when chronically exposed to CWI are limited to endurance athletes [142] with no published studies on elite team-sport athletes. While research on chronic CWI in non-elite team sport athletes does exist [142], we believe these findings are unlikely to apply to elite team sport athletes as the training load and training density are not comparable between settings, i.e. the rationale to speedup recovery by implementing cold modalities is limited when time between sessions allows for athletes to naturally recover. Therefore, the aim of the current study was to investigate the effects of chronic exposure to CWI on physiological and perceptual markers of fatigue in an elite rugby population during an intense three-week pre-season training phase.

## **Methods**

### *Participants*

Twenty-nine professional male rugby athletes volunteered to participate in the current study. Athletes were members of a team that made it to the semi-finals of the super rugby competition in the same year as data collection took place. The super rugby competition is the major competition in the southern hemisphere comprising of teams from Argentina, Australia, Japan, New Zealand and South Africa. The attendance of at least 90% of the planned number of training sessions, without missing two in a row, was a requirement for inclusion in the present study. Athletes were matched by positional group and were randomly divided in one of two groups: A CWI group and a control group (CON). From the initial sample size, six subjects were excluded due to injury or illness. The 23 remaining athletes were included in the data analysis (CWI: n = 10; 6 forwards [60%] 4 backs [40%]; CON: n = 13; 8 forwards [61.5%] 5 backs [38.5%]) (Table 1). Written informed consent was obtained from each participant, and ethical approval was obtained from the Human Research Ethics Committee of the University of Waikato.

**Table 1.** Participants characteristics. Data shown as means  $\pm$  SD.

	CWI group (n = 10)	Control group (n = 13)
Age (years)	22.9 $\pm$ 2.7	22.3 $\pm$ 1.9
Body mass (kg)	105.4 $\pm$ 16.3	110.2 $\pm$ 12.4
Height (cm)	185.6 $\pm$ 5.1	189.4 $\pm$ 7.3
$\Sigma$ 8 skinfolds (mm)	80.2 $\pm$ 17.8	91.4 $\pm$ 28.4
Squat 1-RM (kg)	183.9 $\pm$ 30.1	184.5 $\pm$ 32.2
Bench Press 1-RM (kg)	140.5 $\pm$ 26.5	136.8 $\pm$ 28.5
Chin-ups 1-RM (kg)	144.0 $\pm$ 15.7	135.0 $\pm$ 32.2
Speed 20 m (s)	3.02 $\pm$ 0.19	2.95 $\pm$ 0.18
Yoyo IRTL1	18.2 $\pm$ 1.1	17.3 $\pm$ 1.1

One repetition maximum (1-RM), Intermittent recovery test level 1 (IRTL1)

### *Procedures*

This study occurred during three weeks of the pre-season period and each week consisted of four days of training as described in Table 2. Immediately after each training day, the athletes in the CWI group were exposed to the recovery intervention. Therefore, athletes in the CWI group were exposed to CWI four times in each week, totaling 12 CWI sessions over the duration of the study. The CWI protocol consisted of athletes being immersed for 10 minutes to a level of the iliac crest in an industrial tub filled with water at a fixed temperature of 10 °C (Hayward® EnergyLine pro ENP3M-13A, Dandenong South, VIC, Australia). The duration of the immersion and water temperature used in the current study were based on that proposed in a recent literature review on the effects of different recovery modalities in rugby which included

CWI strategies for rugby players [107]. The athletes in the CON group followed their normal post-training routine (i.e. have a shower and get dressed) and remained at the training facilities until all athletes in the CWI group completed their CWI protocol. Questionnaires and countermovement tests (CMJ) were implemented on the mornings of Day 1 and 4 of each of the three weeks. Saliva samples were collected prior to any food intake on Day 4 each week. The order and time of data collection were maintained throughout the study, and individual wake times were monitored through questionnaires.

#### *Training program*

The training program consisted of four resistance training sessions (two for lower body and two for upper body) designed to increase maximal strength and power (i.e. 3-5 sets of 1-6 RM for core exercises and 3-5 sets of 0-70% 1-RM for power exercises) [145], seven rugby field sessions, two speed sessions and three extra-conditioning sessions per week (Table 2). Given the schedule was similar during the three weeks of the study, the duration of the sessions and the training load is presented as the average of the three weeks in Table 2 and Table 3.

**Table 2.** Weekly training schedule during the three weeks of the study. Resistance training, conditioning and technical-tactical duration (minutes), and qualitative intensity or type of training are described.

		Training period						
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Before		CMJ+QWS			CMJ+QWS+Sa 1			
Morning		Speed session (30') Gym session (LBRT: 75') TT (45'; Moderate)	Gym session (UBRT: 75') TT (45'; Moderate)	Theory sessions	Speed session (30') Gym session (LBRT: 75') TT (45'; Moderate)	Gym session (UBRT: 60') TT (75'; Moderate)	Day- off	Day- off
Afternoon		TT (90'; High) Cond (30'; High)	TT (60'; High)		TT (60'; High) Cond (30'; High)	Cond (50'; High)		

Jumping performance (CMJ); Wellness and soreness questionnaires (QWS); Saliva Sample (Sal); Lower body resistance training (LBRT); Upper body resistance training (UBRT); Technical-tactical session (TT); Conditioning session (Cond).

### *Perceptual measures*

A wellness questionnaire and a lower-body soreness (LB soreness) questionnaire previously used in rugby athletes was implemented on the morning of Day 1 and Day 4 of each week during the period of the study [5]. The wellness questionnaire comprised of five questions to measure perceived fatigue, general muscle soreness, sleep quality, stress levels, and mood state. The lower-body soreness questionnaire was designed to detect muscle soreness at five specific lower-body sites [5]. Both questionnaires used a 5-point Likert scale with 0.5-point increments where 1

represented a low score (e.g. *very sore*) and 5 a high score (e.g. *no soreness*) [5]. A total measure of each questionnaire (i.e. wellness questionnaire and lower-body soreness questionnaire) was calculated from the average of the items [5].

#### *Neuromuscular performance*

In order to monitor neuromuscular fatigue, peak force (N) was measured during a CMJ test performed each morning on Day 1 and Day 4 during the 3-week period (Table 2). Following a standardized warm-up composed of dynamic stretches and movements (e.g. one-leg standing knee flexion, bodyweight squats, bodyweight CMJs), athletes performed three maximal CMJs. Two force plates (PASCO PS 2142, Roseville, CA, USA) were used to measure peak force (PF) at a sample rate of 500 Hz. The force plates were connected to an analog-to-digital converter (SPARKlink, Pasco Scientific, Roseville, CA, USA), which was then connected to a PC and the Pasco Capstone v1.4.0 software (PASCO, Roseville, CA, USA) through a USB port. Each trial started with the subjects standing on the top of the force plates with their knees fully extended and their hands on hips to eliminate the influence of arm swing. Subjects were then instructed to descend to a self-selected depth and to jump as high and quickly as possible [146]. The best trial, determined by peak force, was retained for later analysis. Data obtained with 18 elite rugby athletes demonstrate that PF obtained with the same setup and protocol has an acceptable level of test-retest reliability in a similar cohort (ICC: 0.89; CV: 4.56%) [110].

### *Saliva samples*

Whole saliva samples were collected to monitor weekly changes in cortisol and IL-6. Players expectorated a sample via passive drool into a 50-mL polyethylene tube, which was stored at  $-20\text{ }^{\circ}\text{C}$  until assayed. Cortisol and IL-6 concentrations were determined in duplicate using commercially available enzyme-linked immunosorbent assay kits (Salimetrics, State College, PA, USA) as per the manufacturer's instructions. Cortisol assay sensitivity was  $3.5\text{ pmol}\cdot\text{L}^{-1}$  with intra-assay and inter-assay CV  $< 3\%$ . IL-6 assay sensitivity was  $0.07\text{ pg}\cdot\text{mL}^{-1}$  with intra- and inter-assay CV  $< 10\%$ . Saliva samples for each participant were analyzed in the same assay to eliminate inter-assay variance.

### *Training load*

Locomotor activity of each participant was monitored during all technical-tactical training sessions with a 15 Hz GPS unit (Viper Pod, STATSport, Belfast, UK) incorporated into the players' jersey on the upper thoracic spine between the scapulae. In order to decrease the between-unit variability, the same GPS unit was used by each participant for subsequent sessions. The GPS units were turned on before the warm-up and turned off after the completion of the training sessions. After each training session, the raw data files were analyzed and individual sessions' relative distance (m/min) and high metabolic load distance (HML; distance covered  $> 5\text{ m/s}$  and/or distance accelerating and decelerating over  $2\text{ m/s}^2$ ) were obtained from the company's software (Viper PSA software, STATSports, Belfast, UK). The individual training RPE of the non-running conditioning sessions and the gym training sessions were obtained between 15 and 30 minutes after the completion of the session [137]. The training load

was then calculated as the product of the individual session RPE (sRPE) and the duration of the session using the following formula: Training load = sRPE (1-10) × duration of the session (min) [137]. A total measure of perceived training load was calculated from the individual sum of the non-running conditioning sRPE coupled with the gym training sRPE.

### *Statistical analysis*

All statistical analyses were performed using SPSS 25.0 (IBM Corp., Armonk, NY, USA). Independent samples T-tests or Mann-Whitney tests were conducted to verify the differences between groups (CWI and CON) for the baseline measures (i.e. the first samples collected during the experimental period) for CMJ, LB soreness, wellness, IL-6 and cortisol. These statistical tests were also conducted to determine the differences between groups for athlete characteristics i.e. age, body mass, height, sum of eight skinfolds, squat 1-RM, bench press 1-RM, chin-ups 1-RM, speed over 10-m, Yoyo intermittent recovery test Level 1, all measured the week prior to the beginning of the experimental period.

The differences from baseline measures in CMJ, LB soreness, wellness, cortisol and IL-6 were calculated. A repeated measures ANOVA was performed to determine the effect of different treatments (CWI or CON) over time (day/week) on all measured variables. Analysis of the studentized residuals was verified visually with histograms and also by the Shapiro-Wilk test of normality.

In addition, effect-size statistics were performed for differences between groups from baseline (Day 1 of Week 1) for CMJ, IL-6, cortisol, LB soreness, and total wellness.

For these measures, the standardised change in the mean from baseline for each day was determined and expressed as standardised (Cohen's *d*) effects [147]. Effect sizes were also determined to compare differences between groups for the training load markers in each week. Magnitudes of the standardised effects were interpreted using thresholds of 0.2, 0.6, 1.2 and 2.0 for *small*, *moderate*, *large*, and *very large*, respectively [109]. An effect size  $< 0.2$  was considered *trivial* [109]. Where the 90% confidence limits overlapped *small* positive and negative values, the effect was deemed *unclear* [148].

## **Results**

Athlete characteristics for age, body mass, height, sum of eight skinfolds and performance markers (i.e. maximum strength, speed and aerobic power) are included in Table 1 as means  $\pm$  SD. No significant differences ( $p < 0.05$ ) were found between groups for the athletes' characteristics or measures of training load (Table 3).

**Table 3.** Average weekly training loads for CWI and CON and differences between training groups for Weeks 1, 2 and 3. Data presented as means  $\pm$  SD unless stated otherwise. No significant differences observed between groups for any training load parameter.

	Week 1		$\Delta$ CON – $\Delta$ CWI (Mean $\pm$ 90% Confidence Limit; Effect Sizes)	Week 2		$\Delta$ CON – $\Delta$ CWI (Mean $\pm$ 90% Confidence Limit; Effect Sizes)	Week 3		$\Delta$ CON – $\Delta$ CWI (Mean $\pm$ 90% Confidence Limit; Effect Sizes)
	CWI	CON		CWI	CON		CWI	CON	
Gym sRPE (AU)	441 $\pm$ 61	415 $\pm$ 59	-25.8 $\pm$ 43.7; <i>unclear</i> (-0.39)	440 $\pm$ 60	437 $\pm$ 45	-3.0 $\pm$ 39.7; <i>unclear</i> (-0.05)	596 $\pm$ 66	606 $\pm$ 71	9.3 $\pm$ 49.8; <i>unclear</i> (0.13)
Conditioning sRPE (AU)	359 $\pm$ 29	355 $\pm$ 28	-3.3 $\pm$ 20.7; <i>unclear</i> (-0.11)	269 $\pm$ 29	281 $\pm$ 22	-11.4 $\pm$ 19.3; <i>unclear</i> (0.36)	302 $\pm$ 33	315 $\pm$ 37	13.4 $\pm$ 25.2; <i>unclear</i> (0.37)
Total sRPE (AU)	800 $\pm$ 84	770 $\pm$ 79	-29.1 $\pm$ 59.8; <i>unclear</i> (-0.32)	709 $\pm$ 74	718 $\pm$ 29	8.4 $\pm$ 47.5; <i>unclear</i> (0.10)	898 $\pm$ 89	921 $\pm$ 97	22.7 $\pm$ 67.1; <i>unclear</i> (0.23)
HML (m)	838 $\pm$ 201	839 $\pm$ 139	0.9 $\pm$ 130.4; <i>unclear</i> (0.00)	844 $\pm$ 184	915 $\pm$ 231	71.8 $\pm$ 149.4; <i>unclear</i> (0.36)	1130 $\pm$ 304	1066 $\pm$ 318	7.4 $\pm$ 169.9; <i>unclear</i> (0.03)
Relative distance (m/min)	73.2 $\pm$ 10.8	76.6 $\pm$ 5.3	3.4 $\pm$ 6.6; <i>unclear</i> (0.29)	71.9 $\pm$ 8.5	76.0 $\pm$ 11.46	4.0 $\pm$ 7.2; <i>unclear</i> (0.43)	82.1 $\pm$ 12.0	80.1 $\pm$ 9.0	-2.0 $\pm$ 7.9; <i>unclear</i> (-0.15)

sRPE = Session rate of perceived exertion, AU = Arbitrary unit, HML = High metabolic load

Although results from ANOVA found no interaction for Time  $\times$  Group for any of the measured variables (Table 4), the analysis of the effect sizes demonstrates a *small* effect in favour of CWI on CMJ performance and a *moderate* effect on LB soreness (Table 5).

**Table 4.** Analysis of Variance for the variables of interest with Group (CWI vs CON) as the between subjects' factor and Day (CMJ, LB soreness and wellness) or Week (IL-6 and cortisol) as within subjects' factor. \* represents significant difference.

Test	Source of variation	( <i>df</i> , <i>df<sub>error</sub></i> )	<i>F</i>	<i>p</i>
<b>CMJ Performance (N)</b>	Day	(2,42)	3.666	0.034*
	Group	(1,21)	2.647	0.119
	Day*Group	(2,42)	0.555	0.578
<b>LB soreness (AU)</b>	Day	(2,42)	3.357	0.044*
	Group	(1,21)	2.122	0.160
	Day*Group	(2,42)	1.393	0.260
<b>Wellness (AU)</b>	Day	(2,42)	0.947	0.396
	Group	(1,21)	0.178	0.677
	Day*Group	(2,42)	2.400	0.103
<b>IL-6 (<math>\mu</math>L)</b>	Day	(1,17)	0.055	0.055
	Group	(1,17)	2.845	0.110
	Day*Group	(1,17)	0.232	0.636
<b>Cortisol (<math>\mu</math>L)</b>	Day	(1,16)	0.055	0.483
	Group	(1,16)	2.845	0.882
	Day*Group	(1,16)	0.232	0.337

Moreover, a *moderate* effect of CWI attenuating increases in IL-6 in comparison to CON was observed in the comparison from Week 3 to Baseline (Table 5). No differences between or within groups were observed for Cortisol over the duration of the study (Table 5). Further analysis of the effect sizes revealed that on Day 4 of each week, the athletes in the CON group demonstrated *small* reductions in CMJ performance and wellness scores, and *moderate* increases in soreness, while the athletes in the CWI were able to maintain scores in comparison to Baseline (Table 5).

**Table 5.** Changes in measures of CMJ performance, perceptual soreness and wellness and saliva markers from Baseline (Day 1) to the remaining testing days.

	Week		$\Delta$ CWI (Mean $\pm$ SD; <i>Effect Size</i> )	$\Delta$ CON (Mean $\pm$ SD; <i>Effect Size</i> )	$\Delta$ CON – $\Delta$ CWI (Mean $\pm$ 90% Confidence Limit; <i>Effect Size</i> )
<b>CMJ Performance (N)</b>	Week 1	Baseline	2679.6 $\pm$ 434.8	2916.8 $\pm$ 489.4	237.2
		Day 4 – Baseline	11.3 $\pm$ 179.4; <i>trivial</i> (0.02)	-175.8 $\pm$ 252.7; <i>small</i> (-0.36)	-187.1 $\pm$ 155.5; <i>small</i> (0.38)
	Week 2	Day 1 – Baseline	-96.4 $\pm$ 228.8; <i>unclear</i> (-0.20)	-148.8 $\pm$ 210.2; <i>small</i> (-0.20)	-52.4 $\pm$ 161.1; <i>unclear</i> (0.11)
		Day 4 – Baseline	-77.1 $\pm$ 224.1; <i>trivial</i> (-0.16)	-191.1 $\pm$ 265.2; <i>small</i> (-0.39)	-114.0 $\pm$ 176.1; <i>small</i> (0.23)
	Week 3	Day 1 – Baseline	-34.9 $\pm$ 234.4; <i>trivial</i> (-0.07)	-188.7 $\pm$ 289.4; <i>small</i> (-0.39)	-153.8 $\pm$ 188.4; <i>small</i> (0.31)
		Day 4 – Baseline	-95.6 $\pm$ 201.2; <i>unclear</i> (-0.20)	-263.1 $\pm$ 313.3; <i>small</i> (-0.54)	-167.5 $\pm$ 185.7; <i>small</i> (0.34)
	<b>LB soreness (AU)</b>	Week 1	Baseline	3.6 $\pm$ 0.5	3.6 $\pm$ 0.6
Day 4 – Baseline			0.2 $\pm$ 0.6; <i>unclear</i> (0.30)	0.5 $\pm$ 0.6; <i>moderate</i> (0.88)	0.3 $\pm$ 0.4; <i>small</i> (0.58)
Week 2		Day 1 – Baseline	-0.2 $\pm$ 0.3; <i>small</i> (-0.42)	0.1 $\pm$ 0.5; <i>small</i> (0.20)	0.4 $\pm$ 0.3; <i>moderate</i> (0.62)
		Day 4 – Baseline	-0.2 $\pm$ 0.6; <i>unclear</i> (-0.32)	0.3 $\pm$ 0.6; <i>moderate</i> (0.60)	0.5 $\pm$ 0.4; <i>moderate</i> (0.91)
Week 3		Day 1 – Baseline	-0.3 $\pm$ 0.3; <i>small</i> (-0.58)	0.1 $\pm$ 0.5; <i>small</i> (0.23)	0.5 $\pm$ 0.3; <i>moderate</i> (0.81)
		Day 4 – Baseline	0.2 $\pm$ 0.6; <i>unclear</i> (0.37)	0.4 $\pm$ 0.7; <i>moderate</i> (0.66)	0.2 $\pm$ 0.5; <i>unclear</i> (0.29)
<b>Wellness (AU)</b>		Week 1	Baseline	3.9 $\pm$ 0.7	3.8 $\pm$ 0.4
	Day 4 – Baseline		0.0 $\pm$ 0.4; <i>unclear</i> (0.01)	0.3 $\pm$ 0.4; <i>small</i> (0.53)	0.3 $\pm$ 0.3; <i>small</i> (0.50)
	Week 2	Day 1 – Baseline	0.0 $\pm$ 0.5; <i>unclear</i> (0.03)	0.1 $\pm$ 0.4; <i>trivial</i> (0.11)	0.0 $\pm$ 0.3; <i>unclear</i> (0.08)
		Day 4 – Baseline	0.2 $\pm$ 0.5; <i>small</i> (0.36)	0.2 $\pm$ 0.6; <i>small</i> (0.43)	0.0 $\pm$ 0.4; <i>unclear</i> (0.07)
	Week 3	Day 1 – Baseline	0.0 $\pm$ 0.3; <i>unclear</i> (0.07)	0.1 $\pm$ 0.3; <i>trivial</i> (0.11)	0.0 $\pm$ 0.2; <i>unclear</i> (0.04)
		Day 4 – Baseline	0.3 $\pm$ 0.6; <i>small</i> (0.55)	0.2 $\pm$ 0.4; <i>small</i> (0.42)	-0.1 $\pm$ 0.4; <i>unclear</i> (-0.13)
	<b>IL-6 (<math>\mu</math>L)</b>	Week 1	Baseline	18.3 $\pm$ 6.5	19.7 $\pm$ 7.8
Week 2		Day 4 – Baseline	-1.7 $\pm$ 6.8; <i>unclear</i> (-0.23)	2.6 $\pm$ 3.0; <i>unclear</i> (0.35)	4.2 $\pm$ 6.0; <i>unclear</i> (-0.58)
Week 3		Day 4 – Baseline	-3.1 $\pm$ 5.4; <i>small</i> (-0.42)	3.0 $\pm$ 10.1; <i>unclear</i> (0.41)	6.1 $\pm$ 6.5; <i>moderate</i> (-0.83)
<b>Cortisol (<math>\mu</math>L)</b>	Week 1	Baseline	0.84 $\pm$ 0.36	0.61 $\pm$ 0.19	-0.23
	Week 2	Day 4 – Baseline	-0.01 $\pm$ 0.32; <i>unclear</i> (-0.03)	0.06 $\pm$ 0.12; <i>trivial</i> (0.19)	0.07 $\pm$ 0.22; <i>unclear</i> (-0.22)
	Week 3	Day 4 – Baseline	0.01 $\pm$ 0.32; <i>unclear</i> (0.02)	-0.03 $\pm$ 0.16; <i>trivial</i> (-0.10)	0.04 $\pm$ 0.23; <i>unclear</i> (-0.12)

## Discussion

The main finding from the current study is that the chronic exposure to cold water immersion over a pre-season phase in elite rugby athletes showed no detrimental effect to performance or recovery. In fact, there was a *moderate* effect in favour of CWI for attenuating increases in muscle soreness when compared to CON (Table 5). The beneficial effects of CWI were also extended to performance in the CMJ and IL-6 values, as demonstrated by the *small* and *moderate* effects, respectively (Table 5). While the acute effects of CWI have been previously investigated in elite rugby athletes [9], this study is the first to show the positive effects of chronic exposure to CWI in elite rugby athletes in terms of neuromuscular performance and immune function [107].

Delayed onset of muscle soreness (DOMS) is a well-documented outcome occurring from exercise-induced muscle damage, with a recent meta-analysis demonstrating that CWI is beneficial for reducing DOMS after exercise strenuous enough to induce damage [80]. Specifically in rugby, previous research observed that CWI decreases muscle soreness and markers of muscle damage, such as creatine kinase clearance, measured 1, 18 and 42 h post-match when compared to active recovery [9]. Although the ANOVA revealed no significant treatment interaction, our findings support the beneficial effect of CWI reducing muscle soreness with *moderate* effects sizes observed between groups (Table 5) over a three-week pre-season training phase. Athletes in the CON group reported higher scores of lower body soreness (i.e. *small* to

*moderate* effect sizes) than athletes in the CWI (i.e. *small* negative effect sizes). It is important to mention that a lack of statistical significance ( $p > 0.05$ ) does not necessarily demonstrate that there is no worthwhile effects in the athletic field, specifically at the elite level where sample sizes may be limited, and where small changes in performance from training interventions can still yield meaningful results [148].

Muscle soreness has been demonstrated to be related to reductions in neuromuscular performance in rugby athletes [5,8], with skeletal muscle damage proposed as a causative factor [128]. Exposure to cold, and CWI in particular, has been demonstrated to enhance recovery in neuromuscular function in rugby [107]. In our study, the beneficial effects of CWI attenuating decrements in neuromuscular function (i.e. CMJ peak force) were demonstrated by a *small* effect in favour of the CWI group (Table 5). These results are in concordance with previous literature demonstrating a beneficial effect of CWI enhancing neuromuscular performance for up to 48 h after rugby training or competition [9,21]. Moreover, our findings are consistent with findings from Roberts et al. [144] that demonstrated that CWI enhances the recovery in muscle function as demonstrated by the capability to perform more volitional work in the squat exercise.

One of the key questions this study aimed to answer was whether CWI would attenuate the fatigue accumulated in response to the high week-to-week training load experienced by elite rugby athletes during a pre-season phase of training. Neuromuscular performance decreased for the CON group on the first day of Week 3

(i.e. post ~65 h of no training) from Baseline (-6.9%). In contrast, for the CWI group, CMJ was only slightly decreased on the first day of Week 3 (-1.32%), with a *small* effect being observed for the differences between groups (Table 5). These differences suggest that during Week 3, athletes in the CWI group were better recovered and able to maintain training intensity. Moreover, a trend towards lower levels of IL-6, associated with a *moderate* effect size in favour of CWI, demonstrates that CWI may attenuate IL-6 over the longer term. It has been suggested that if high training loads occur without adequate recovery, a chronic increase of circulating cytokines (e.g. IL-6) can occur, increasing the risk of maladaptation [149]. For example, Anderson et al. [150] found a chronic elevation in IL-6 in collegiate American football athletes following a high intensity 6-week period, demonstrating that when training loads are high, IL-6 can be chronically increased. Together with the decrement in CMJ performance observed in the CON group, and the *moderate* increase in IL-6 in the comparison between groups (i.e. CON > CWI) it is possible that athletes in the CON group were not able to positively respond to training load [149].

Our findings are supported by those from Halson et al. [142] whom observed a likely beneficial effect of CWI on cycling performance in highly-trained endurance cyclists during a 21-day intensification phase, followed by an 11-day taper period. In rugby, the investigation of the chronic effects of CWI is limited to the one study that observed no beneficial effects of CWI [27]. However, as previously discussed, the results from that study are not necessarily transferable to elite team-sport athletes as the training load was relatively low. The participants of our study are professional athletes that were

exposed to a very dense training schedule (e.g. two or more training sessions occurring every training day) (Tables 2 and 3). Therefore, CWI may aid in the maintenance of high mechanical outputs (e.g. high values of force, power and speed) during periods with increased training volume. Particularly in this study, on Day 4 of each week, the athletes in CON had a decrease in neuromuscular performance, suggesting that these athletes may have underperformed during the speed session performed on Day 4, due to an increased level of fatigue. Moreover, when CWI is implemented with athletes exposed to a high-density training schedule, it may prevent maladaptive responses from training.

It is important to note some limitations of this study. Similar to other research investigating the effects of CWI in rugby, the small sample size (10 and 13 athletes in CWI and CON, respectively) may be a limiting factor in the present study. The inference-based analysis method used in this study is often used in research with small samples of elite athletes to overcome this limitation [148]. Given the limited access to a greater sample size, it was not possible to include a placebo group in our study. Previous research has demonstrated that a thermoneutral water immersion placebo is as effective as CWI on the improvement of acute muscle function and perceptual measures. Therefore, the potential for placebo effect in the current study cannot be discounted [151]. Another limitation of the current study is that saliva was collected on Day 4 of each week where athletes had ~36 hours to recover from the previous training session. Previous research has demonstrated that cortisol and IL-6 increase significantly after an elite rugby match, but values decrease to baseline values 14 hours

post-match [152]. While the IL-6 and cortisol were likely to increase after exercise, it is unlikely that they would still be elevated 36 hours after exercise (i.e. no training occurred between Days 2 and 4), therefore changes in these markers reflect a chronic (i.e. week to week) exposure to training loads [152]. Another limitation was fact that the temperature used for the CWI (10 °C) was not individualized. This standardized approach was necessitated by the practicalities of working in the elite sport environment but should be noted as a potential limitation as differences in body composition (i.e. muscle mass and body fat) and the ratio between body surface area and body mass (BSA:BM) lead to different responses in body temperature [153]. It could be expected that if CWI temperature was individualized (i.e. lower CWI temperatures for subjects with a greater BSA:BM and fat mass), then the beneficial effects of CWI on recovery could be increased [154].

## **Practical applications**

When athletes are exposed to high volumes of training with limited time to recover between training sessions, practitioners should consider the implementation of CWI in order to speed up recovery of neuromuscular performance and improve perceptions of lower body DOMS. Furthermore, if high volume training is prolonged for several weeks (e.g. three or more weeks), CWI may prevent maladaptive responses from training.

## **Conclusions**

Our study is the first to demonstrate that CWI may provide a beneficial effect to recovery in both the acute and chronic setting when elite team-sport athletes are exposed to high training loads. As previously mentioned, chronic exposure to cold modalities has been reported to both blunt acute anabolic pathways associated with adaptations to training [88], and enhance recovery of submaximal muscle function [144]. Here we demonstrate that CWI may enhance recovery in elite rugby athletes, allowing the athletes to perform at greater intensities which may in turn, lead to a greater overall adaptive stimulus [142]. Therefore, in order to further clarify this question, future research investigating the chronic effects of CWI within an athletic population should include measurements of muscle size or markers of hypertrophy simultaneously with measures of performance over a longer period of time (e.g. > 4 weeks), although it should be noted that in an elite population, performance metrics (rather than hypertrophy per se) are the key outcome measures.

## CHAPTER SIX

### Practical applications of water immersion recovery modalities for team sports

Tavares F, Walker O, Healey P, Smith TB, Driller M. Practical applications of water immersion recovery modalities for team sports. *Strength and Conditioning Journal*. 2018;40(4):48-60.

In addition to the essential components of recovery (sleep, rest, hydration, and nutrition), cold therapies (e.g. cold water immersion, contrast water therapy, cryotherapy) are the most utilized recovery modalities to enhance recovery within an athletic population. Acutely, cold modalities have been shown to improve recovery by decreasing markers of muscle damage, inflammation, and perceived muscle soreness, pain, and fatigue while improving muscle function. Less is known about the effects of cold modalities over a longer time frame, with some research demonstrating a decrease in the anabolic response, suggesting a decreased adaptation to training. In **Study Five** we have demonstrated that when training load is high and time for recovery is reduced, CWI can enhance recovery and attenuate the effects of accumulated fatigue from training week to training week. Considering the results from our previous study (**Study Five**), **Study Six** aimed to review the current knowledge on the different protocol characteristics and individual factors that may contribute to responses of cold therapies,

providing practical recommendations based on external factors, such as the phase of the season, the density of the weekly schedule, and the athletes' goals.

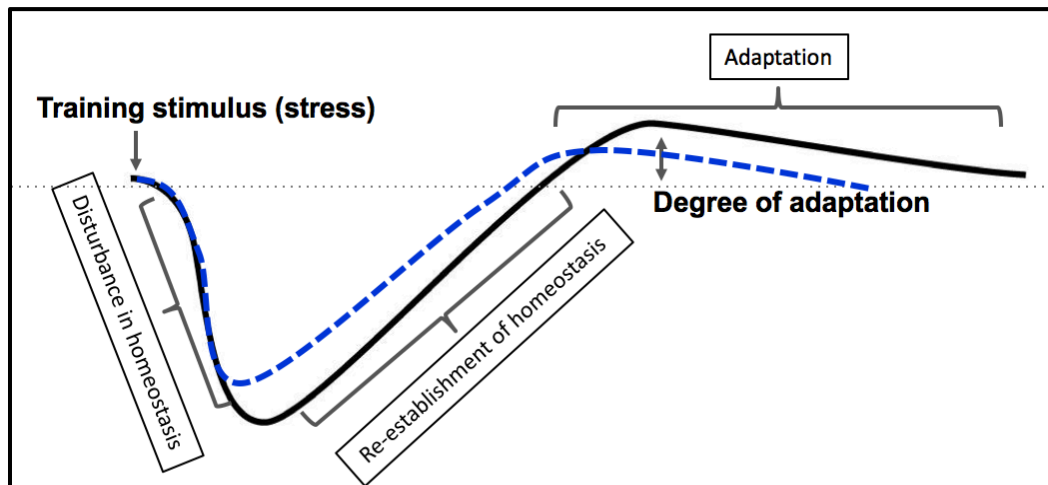
## **Abstract**

In addition to the essential components of recovery, cold therapies are the most utilized modalities to enhance recovery within an athletic population. Whilst the benefits of cold therapies are well documented in the scientific literature, recent research has demonstrated some potential harmful effects of such modalities as well as individual responses to similar protocols. This paper reviews the current knowledge on the different protocol characteristics and individual factors that may contribute to responses of cold therapies, providing practical recommendations based on external factors, such as the phase of the season, the density of the weekly schedule and the athlete's goals.

Keywords: cold water immersion, contrast baths, performance

## **Introduction**

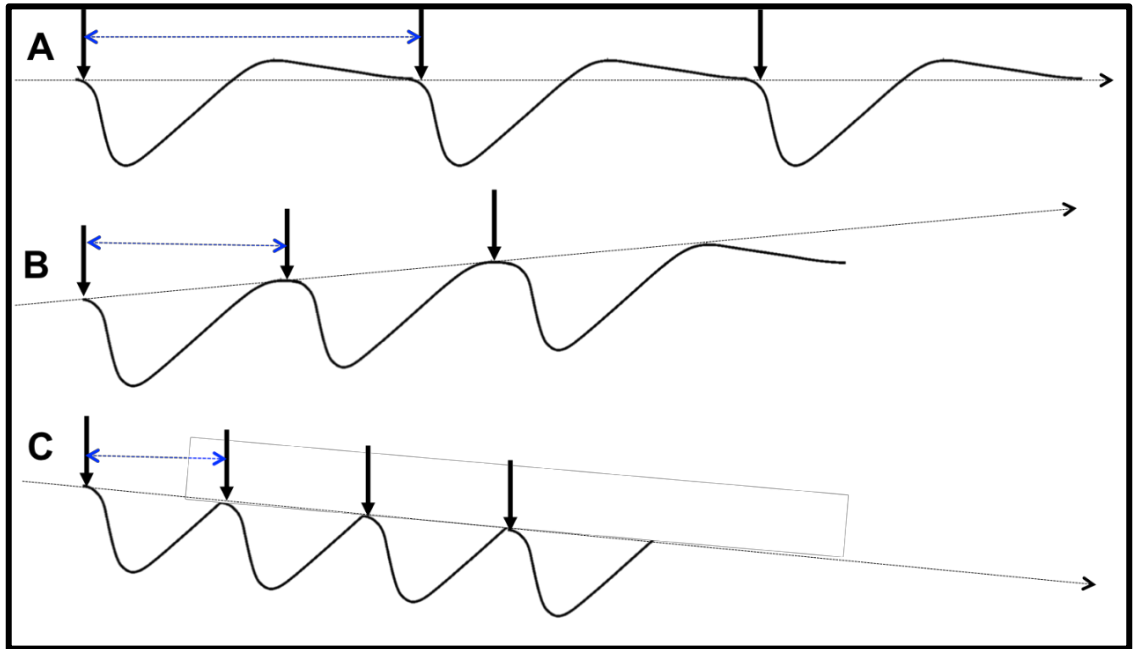
From a physical perspective, the training stimulus can be considered as a challenge to the organism, as it disturbs homeostasis [32,155] and typically elicits a catabolic response. Moreover, a temporary reduction in performance after different training stimuli has been extensively demonstrated in the sport science literature [32,156]. Training stimuli are structurally implemented in a way that allow for athletes to recover between sessions or training phases, leading to physiological adaptations and enhanced performance [12]. However, one needs to understand that responses to the training stimuli are not only individual but can also vary within the same individual during different periods of their training career [157]. For example, the state of anxiety and vigour domains were found to differ between different phases of the season in Paralympic athletes [157]. Moreover, allostasis (e.g. processes from the organism involved in the responses to daily events) leads to different psychobiological responses [158] that play a role in the different physiological systems responses and adaptations to exercise [159]. Therefore, it is well established that acute responses and chronic adaptations are dependent of a series of complex biological processes [155], that are influenced by a diversity of factors including training related aspects (e.g. training status), physical aspects (e.g. genes and ethnicity) and psychological aspects (e.g. psychosocial stress). While it is beyond the scope of this review to explore in depth the biological processes involved in training responses and adaptations, and the factors affecting such processes, a rationale is presented to justify the role that cold recovery modalities may have on enhancing recovery during certain periods of training.



**Figure 1.** Schematic representation of the training response. The blue line represents the enhancement in recovery [80,168] and the potential blunting effect on muscle adaptation from the use of cold recovery modalities [88,93].

When a training stimuli is applied, a disturbance in the internal equilibrium is expected (Figure 1). During this period, acute fatigue is experienced and performance is inhibited [32,156]. This reduction in performance is temporary, as the organism starts to resist the disturbance to homeostasis, and seeks to re-establish equilibrium. From an exercise standpoint, the resistance phase is generally termed “recovery”. Bishop and colleagues [32] categorized this recovery period into three categories (i.e. immediate recovery, short-term recovery, and long-term recovery). For the purpose of this review, recovery will be defined as the physiological occurrences between the end of one training stimulus and the beginning of the next [32,107]. The magnitude of the performance re-establishment period is affected by the impact of the training stimulus and the characteristics of recovery (e.g. strategies to decrease the impact of the training stress). Moreover, as aforementioned, training and recovery responses will also be affected by

the allostatic load an athlete is exposed to [159]. It is well described in literature that an allostatic overload leads to inadequate biochemical responses as a protective mechanism that may limit responses and adaptations from training [158]. Adaptations in these psychobiological responses differ between subjects. For example, it was demonstrated that athletes can tolerate psychosocial stress better than untrained subjects [160]. Ultimately, changes in performance arising from the training stimulus will be dependent on the combination of the biological processes (e.g. physiological, psychobiological), given the combination of these processes favours adaptation, an improved performance is expected. If this cycle is repeated and sequenced with appropriate recovery, over time an increase from the baseline will occur for those physical components of fitness specific to the training stimulus, leading to positive adaptation [32] (Figure 2B).



**Figure 2.** Schematic representation of hypothetical training capacity / preparedness to train (vertical axis), according to the three different intervals between training stimulus (blue arrow). A: the interval is too long and no adaptation occurs (undertraining); B: the interval is appropriate and adaptation will occur; C: the interval is too short and the training capacity decreases as the accumulated fatigue increases (over-reaching) [32,33,161].

The timing for the next training stimulus must be carefully programmed by coaches in order to allow for athletes to recover between sessions or between training phases (Figure 2B) [32,162]. If the recovery time between two training sessions is too short, training adaptation will be affected (e.g. insufficient recovery will result in decreased performance; Figure 2C), and the risk of over-reaching (OR), overtraining (OT) and illness and injury is increased [32,161,162]. However, from a physiological perspective, the target system(s) require a frequent application of training stimulus in order to adapt (Figure 2A). Therefore, training adaptation will be highly dependent on the equilibrium between the training stimulus, the allostatic load and the recovery

characteristics [33]. For this reason, recovery is an essential factor in the exercise-adaptation cycle [32].

Highly trained team-sport athletes frequently train two or more times daily for two or more consecutive days [5,6,141]. The high density of the weekly schedule results in a limited time for recovery between training sessions. Therefore, fatigue levels (e.g. muscle damage, delayed onset muscle soreness, performance) may not return to baseline between training sessions [5, 134, 136,163]. The fact that fatigue does not return to baseline between training sessions may lead to an excessive level of accumulated fatigue during the week or training phase [163] that could ultimately result in under-performance during the match or lead to an undesirable fatigue status (Figure 2C) [12,164]. Previous research performed on team sports have demonstrated high levels of accumulated fatigue during the training week (e.g. volleyball [163], basketball [136], and soccer [134]). In order to speed-up recovery, sport scientists and coaches frequently implement recovery strategies (Figure 1) [37,107]. Cold modalities such as cold-water immersion (CWI) and contrast water therapy (CWT) are one of the most common acute recovery strategies used by team sport athletes [42,141]. For this reason, there are several interventional research studies [7,163] and reviews [153,165,166] on the efficacy of cold modalities for recovery.

## **Cold modalities and physiology**

The most commonly used cold modalities to enhance recovery within team-sport athletes are CWI and CWT [42,107]. Another method of cold exposure utilises whole

body cryotherapy (WBC) [69,167]. Whole body cryotherapy involves short exposure (2-4 minutes) to extreme cold (-110 to -140 °C) induced by air [69,167]. In addition to the somewhat invasive-nature of WBC, this technique is very expensive and therefore not regularly used by teams and/or athletes. In comparison, water therapies (CWI and CWT) can be low-cost and more widely used in team sports [42, 107,141]. Therefore, for the purpose of this practical review, we will focus on the use of water immersion for recovery. The typical CWI and CWT protocol characteristics implemented within team-sports can be found in Table 1 and are discussed later in this review.

**Table 1.** Typical CWI and CWT protocol characteristics. Adapted from refs: [80, 107,168]

<b>Weeks</b>	<b>Temperature</b>	<b>Sets</b>	<b>Total duration</b>	<b>Immersion</b>
<b>Cold-water immersion</b>	8 – 15°C	1 – 3	5 – 15 min	Whole body or lower body only
<b>Contrast water therapies</b>	Cold: 8 – 15 °C Hot: 33.5 – 45 °C	3 – 6 cold and hot	9 – 15 min (1 min cold; 1 – 3 min hot)	

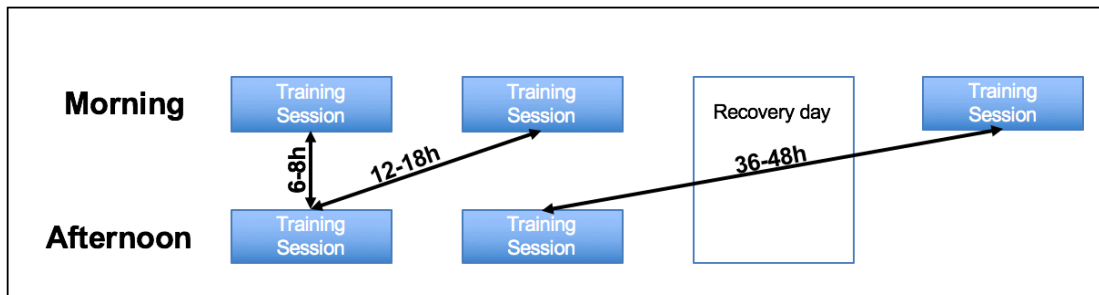
The biochemical and physiological mechanisms underpinning the enhancement of recovery due to cold exposure has been extensively reviewed elsewhere [81, 143,153]. Briefly, the exposure to cold decreases skin, core and muscle temperatures [143]. The reduction in temperature leads to vasoconstriction which in turn decreases swelling and acute inflammation from muscle damage [77–80]. Moreover, a reduction in nerve

conduction properties and a decrease in muscle spasm and pain are also expected due to reduction in tissue temperature [77–79]. In addition, cold modalities involving immersion in water lead to hydrostatic pressure-induced changes in blood flow, with some research suggesting a beneficial effect by promoting metabolic waste removal [81]. Nevertheless, as reviewed by Ihsan et al. [169], previous research observed no effects on metabolite clearance, therefore other mechanisms than metabolite clearance may promote recovery following cold exposure. During CWT, athletes alternate between cold and hot water immersion. Hot water increases vasodilation, leading to an increase in blood flow and facilitation of oxygen and antibody supply, metabolite clearance and a reduction in muscle spasm and pain [77–79]. Alternating, cold and hot water immersion (i.e. CWT) results in both vasoconstriction and dilation that may lead to changes in blood flow and reduction in swelling, inflammation and muscle spasm [77–79].

As cold exposure appears to alter neurophysiological mechanisms, the type of application [168], temperature [165,166], duration [170] and immersion depth [91,171] utilized in various cold water therapy protocols is expected to have an important impact on the responses (e.g. decrease in the core temperature [143]), and thus, the overall recovery process. The characteristics of the water immersion protocols will be discussed later in this article.

## Acute and chronic effects

When strength and conditioning coaches explore the effects of a recovery modality it is recommended to investigate both the acute and chronic effects [107]. The acute effects refer to the changes occurring in a short-time frame, with measurements of fatigue being collected at different time points after a fatiguing task (e.g. match or training session) [9,21]. The time points used in research include normally one or more of the following periods: a) between sessions within the same training day (i.e. up to 6-8 h) [7,172]; b) between a late session of one day and the early session of the following day (i.e. 12-18 h) [9,21]; c) or the time between two sessions separated by a recovery day (~36 h) [9,28].



**Figure 3.** Rationale for the time-frames typically utilized in studies investigating the effects of water immersion recovery modalities [7, 9, 21, 28,172].

Although monitoring the acute time-frame changes on different markers provides the rationale for implementing a given recovery modality, one should not neglect the effects on the longer time-frame [107]. Tracking changes over longer periods (e.g. throughout various weeks) will provide important information concerning the chronic effect of certain recovery modality use [141,142].

## **Acute effects of cold water therapies**

Cold modalities (i.e. CWI and CWT) have been associated with an enhanced recovery as observed by the decrease in muscle damage makers [9,20] and perceptual levels of fatigue, wellbeing and soreness [7,9]. Responses in delayed onset muscle soreness (DOMS) are of particular interest as an increase in muscle soreness is associated with structural damage to the skeletal muscle and consequent disorganisation of the myofilament alignment which in turn is associated with loss of neuromuscular function [120,128]. Therefore, cold modalities are thought to enhance the re-establishment of muscle function post-exercise [7, 9,21]. However, temporary decreases (e.g. immediately after fatiguing exercise) in neuromuscular performance associated with a reduction in the neural drive and enzymatic activity have been reported previously [21]. Ultimately, an increase in muscle function (e.g. mechanical output), perceived muscle soreness and wellbeing is of utmost importance for athletic performance. Nevertheless, equivocal results have been found regarding the acute effects of cold therapies on recovery. While some studies demonstrated a beneficial effect of cold modalities [7, 9,20,21], others failed to find benefits [25,28]. Different variables (e.g. sex, body composition, etc.) have been suggested to account for the individual responses commonly observed [153].

## **Chronic effects of cold water therapies**

While the majority of studies support the acute benefits of cold modalities on recovery, some literature suggests that chronic use of such modalities can negatively influence

training adaptation [88,93]. The acute fatigue and associated metabolites arising from exercise has an important role on the signalling of anabolic processes [126]. For example, Roberts et al. [88] observed a decrease in the activity of the mammalian target of rapamycin (mTOR) pathway and satellite cells after 10 minutes of CWI at ~10 °C. Given this, implementing cold recovery strategies may lead to a decrease in the training adaptations [88,93]. The beneficial acute effects of cold modalities and the potential for reduced muscle adaptations in their use in the chronic setting has led to an extensive debate and questioning from practitioners on implementing cold modalities to enhance recovery. Therefore, two theories have been proposed for the usage of cold modalities [142]: 1) cold recovery modalities allow for athletes to perform subsequent training sessions with a greater quality/quantity (i.e. greater training load) leading to a greater response/adaptation stimulus [7, 9,20,21]; and, 2) cold modalities may decrease adaptations to training via a reduction in protein synthesis response [88,89,173].

Nevertheless, several limitations have been raised regarding previous research investigating the chronic effects of cold modalities and their practical application to athletes [107,142]. Briefly, cold protocols used were considerably more aggressive to those used in practice (e.g. 40 min in 5 °C water); the characteristics of the subjects (untrained or recreationally trained) were different from an athletic population; training load was fixed (e.g. load lifted was fixed to a % of the maximum) in which subjects were not allowed to lift heavier even if they could. Moreover, the training frequency (2-3x training sessions per week) used in these studies potentially allow for full recovery between sessions, limiting the rationale for the inclusion of cold modalities.

In addition, recent research does not support the notion that CWI reduces inflammation, at least compared to active recovery [174–176]. Given these limitations, further research on the chronic exposure to cold modalities have been recently suggested [142]. It is also important to mention that chronic exposure to cold recovery modalities have been associated to an increase in endurance performance within highly trained athletes [142]. One of the possible mechanisms suggested for the beneficial effect of cold exposure [142] is the increased response of transcriptional coactivator, peroxisome proliferator–activator receptor-gamma coactivator (PGC)-1 alpha to cold temperatures [177]. The PGC-1 $\alpha$  is involved in the regulation of the mitochondrial function and oxidative metabolism, therefore it has been suggested as a potential justification for the improvements observed from CWI in highly trained cyclists [142]. Nevertheless, further investigations in this and other mechanisms are necessary to understand metabolic responses to cold recovery modalities.

## **Designing the water immersion program**

The periodization of recovery, in particular, the use of cold modalities, should be carefully designed, just as psychological, nutritional, physical, technical and tactical components are carefully planned and implemented [153]. Previous research have highlighted that recovery modalities should be added as a supplement to the essential components (i.e. sleep, hydration, rest and nutrition) [107]. The perceived importance of different recovery modalities in 507 male athletes who have ranked nutrition, sleep and hydration within the top six recovery modalities [38]. In order for one to

incorporate cold modalities within the recovery program, practitioners must account for the protocol characteristics, external factors such as the phase of the season, and individual factors such as sex and body composition (Table 2) [107,153]. As previously mentioned, there is a rationale for an improvement on endurance performance from exposition to cold recovery modalities [142], nevertheless, research is inconclusive. Therefore, the external factors section was based on requirements for neuromuscular performance and adaptation.

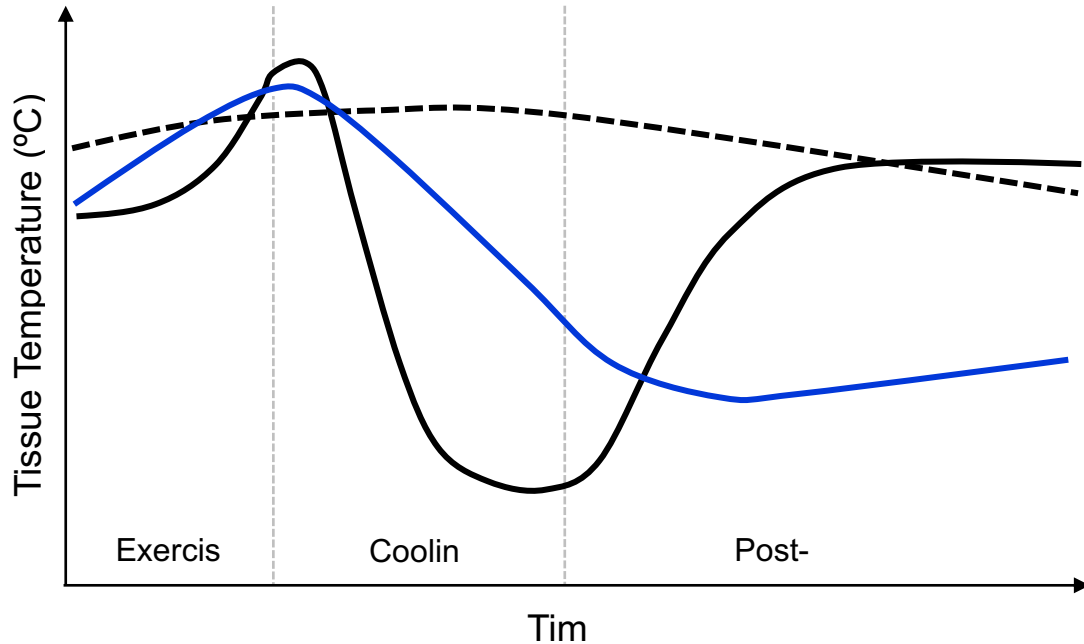
**Table 2.** Protocol characteristics, individual and external factors to be considered when designing a water immersion recovery protocol.

<b>Protocol characteristics</b>	<b>Individual factors</b>	<b>External factors</b>
Duration of exposure to cold	Physique traits	Phase of the season
Type (CWT / CWI)	Sex	Density of the weekly schedule
Immersion depth	Age	Goals of the athlete (long-term and short-term)
Temperature used		

## **Protocol characteristics**

### *Temperature*

Figure 4 displays the temperatures changes in different tissues (skin, deep muscle and the core) before, during, and after various forms of cryotherapy (see Figure 2 of ref: [143]). It is clear that superficial tissues (e.g. skin) cool quicker than deeper tissues (e.g. core) and also return to their pre-cooling temperatures at a faster rate [143].



**Figure 4.** Temperature change at the skin (black full line), core (black dashed line) and deep intramuscular (blue line) sites during exercise, cooling and post-cooling. Adapted from ref: [143].

As cold exposure appears to reduce intramuscular inflammation and impair anabolic signaling [88,174], exposure to colder temperatures is expected to cause a greater reduction in the inflammatory response. The potential caveat to this is that a greater reduction in the inflammatory response will lead to a larger attenuation in the anabolic signaling pathways.

The results of two recent studies (one meta-analysis and one randomized control trial) suggest that there may be an ideal zone for water temperature during CWI (between 11-15 °C) when attempting to optimize recovery [165,166,178]. If true, it may suggest

that lower temperatures (e.g.  $\leq 10$  °C) could blunt the inflammatory and anabolic responses to an extent which may be counterproductive to recovery and adaptation.

### *Duration*

The duration of exposure is also likely to have an impact on the magnitude of the recovery effect. When water temperature remained constant, longer CWI durations have been shown to reduce blood flow and tissue temperature more so than shorter durations [170], reinforcing the fact that tissues cool down in a gradual manner, as opposed to instantaneously. Recall from Figure 4 that superficial tissues (e.g. skin) cool quicker than deeper tissues (e.g. core), with skin reaching its minimum temperature after 8-9 minutes of cooling when using an ice-pack [179], and deeper tissues reaching minimum temperatures much later, even after the cold exposure has finished [180]. As a result, duration should be an important factor considered when attempting to reduce the inflammatory process of deeper tissues. Given this information, it becomes obvious that the exposure duration also plays a significant part in the intensity of the exposure (i.e. increased duration equals greater intensity).

It is also important to understand that superficial tissue temperatures reduce and re-warm significantly quicker than deeper tissues [143]. As a result, repeated exposures (e.g. 2 x 5-minutes with  $> 10$ -mins between-bouts [180]) may be a more effective method than a constant exposure (e.g. 1 x 10-minutes) for reducing deep tissue temperatures.

### *Type*

When considering the application of either CWI or CWT, it is important to understand the different neurophysiological and psychological effects each of these will have on the body.

Results from a recent meta-analysis demonstrate that CWI is an effective strategy to reduce DOMS and improve recovery in muscle power [80]. Similar results to the ones found for CWI were also reported in a meta-analysis investigating the effects of CWT [168]. When CWI and CWT were compared, no differences between interventions were observed in the levels of muscle soreness or muscle pain [168]. No differences were reported for creatine kinase (CK) at any time-points (< 6 h up to 72 h post-exercise), lactate dehydrogenase (< 6 h and 24 h post-exercise), myoglobin (24 h post-exercise) and inflammatory markers (CRP and IL-6; 24 and 48 h post-exercise) [168]. Nevertheless, a trend was observed for a greater CK removal (all time-points) after CWI in comparison to CWT [168]. Cold water immersion has also been demonstrated to be beneficial in comparison to CWT on lactate dehydrogenase clearance after 48 and 72 h [168]. For changes in strength and power, the differences between CWI and CWT are inconclusive [168]. Lastly, in a study which compared the effects of CWT (alternating 1 min immersed in water baths at 38 °C and 1 min at 15 °C for a total of 14 min) to contrast shower therapy (alternating 1 min exposure to shower with water at 38 °C and 1 min at 18 °C for a total of 14 min) and a passive intervention in elite netballers, the authors found no differences in performance among conditions [181]. Nevertheless, perception of recovery was enhanced in the CWT and contrast shower therapy in

comparison to passive recovery. The findings from this study demonstrate that given the limitations in facilities and logistics in team sports, using contrast shower therapy can improve perception of recovery to the same extent as CWT [181].

In conclusion, when comparing the abilities of CWI and CWT for enhancing recovery, numerous studies have reported CWI as being superior [168]. The fact that CWI have been shown to be superior to CWT may not be surprising as CWT only exposes athletes to ~5 minutes of cold, therefore, the potential for attenuating the inflammatory process is reduced with such short exposure times. Again, the flipside to this however, is that the potential for blunting adaptation is reduced because the inflammatory response is barely affected. For these reasons, CWT is expected to be less intense in terms of reducing the inflammatory and anabolic responses than CWI.

#### *Immersion depth*

The immersion depth during water therapies is likely to have an effect on the intensity of the exposure in one of two ways: 1) the deeper the immersion, the greater the impact of hydrostatic pressure upon the body; and 2) during deeper immersion, a larger surface area is in contact with the cold, meaning more heat transfer from the body to the water, and thus having a greater thermal stress.

During immersion, the effects of hydrostatic pressure cause venous and lymphatic compression [79], which ultimately lead to an increase in cardiac output and stroke volume [182]. Whilst immersion depth appears to have no impact upon muscle strength recovery, power output, inflammatory markers, or muscle soreness [183], increasing

cardiac output and stroke volume may still have beneficial effects on recovery by improving nutrient delivery and facilitating the removal of metabolites [81].

With regards to immersion depth and surface area, whole body immersion appears to reduce core temperature to a greater extent than lower-body immersion alone [91,171]. Interestingly, immersion into very cold water temperatures may actually counteract some of the positive effects caused by the hydrostatic pressure. It is well-known that cold water induces vasoconstriction [77–80] and upregulation of the parasympathetic nervous system [184], both of which lead to a reduction in heart rate and thus cardiac output. The reduction in cardiac output response causes the body to reduce peripheral blood flow, prompting increases in central metabolism to maintain this core temperature [79]. So, whilst hydrostatic pressure increases cardiac output and stroke volume, cold water may have an opposing effect by causing the body to reduce peripheral blood flow in an attempt to preserve energy and maintain core temperature. It is believed that increased central metabolism enhances the production of waste products and erodes energy stores, both of which are considered negative and unwanted effects after exercise, and when attempting to enhance recovery [79].

Due to the pressure gradient of water, it is expected that increases in immersion depth are associated with further increases in venous and lymphatic compression, in addition to elevations in stroke volume and cardiac output. As exposure to larger surface areas causes an increased energy loss and thus increases the thermal stress, it may be suggested that greater immersion depths increase the intensity of the modality.

## **Individual factors**

The individual factors of age, sex, psychological and physique traits lead to different responses to cold modalities [153]. Essentially, differences in body composition (i.e. muscle mass and body fat) and the ratio between body surface area and body mass (BSA:BM) seem to justify individual responses to cold [153]. Fat provides greater insulation to thermal transfer in comparison to skin and muscle, therefore, it is expected that fat has a role when athletes are exposed to cold/hot water [185]. Moreover, body mass increases heat production and retention [186]. Nevertheless, greater body mass is associated with greater body surface area. Knowing that evaporation, convection and conduction of heat are dependent on BSA, it is expected that larger BSA leads to increases in heat exchange [153]. Given this, it has been suggested that BSA:BM be included in research exploring thermal effects in subjects with different physique traits [153,185]. While greater BSA:BM facilitates heat loss, lower BSA:BM facilitates heat retention [153]. Increases in the BSA:BM ratio can occur from either an increase in the BSA, a reduction in BM, or both. These characteristics are particularly important in sports where body composition and size are considerably different (e.g. rugby, American football). Moreover, given the association between sex and body fat or BSA:BM (i.e. females > males [187]), different responses to water immersion recovery protocols are expected. Furthermore, one should also realise that skin temperature ( $T_{sk}$ ) and core temperature ( $T_c$ ) are altered across the menstrual cycle, with higher temperatures during the luteal phase in comparison to the follicular phase [188]. Although these individual factors have been recently identified in the literature [153],

the dose-response relationship according to these individual factors has yet to be explored. Briefly, subjects with lower BSA:BM and greater fat mass should be exposed to more intense cold protocols. Given that it is difficult to have cold baths with different temperatures within the same environment, increasing the duration of the protocol is probably the more practical way to increase the intensity when individualization is desirable. Another important factor when incorporating cold modalities is the athletes' belief of efficacy of a given modality [141], as exposing an athlete to a modality he or she dislikes and do not believe in may lead to a cascade of psychobiological responses that are harmful for adaptation [158]. Future research should aim to understand the physiological responses from athletes who believe compared to those who do not believe in cold modalities.

### **External factors**

#### *Phase of the season (goals of the phase)*

From a resistance training perspective, during periods where increases in muscle mass and maximal strength are a key goal (e.g. off-season and pre-season), moderate to high-repetition protocols are normally implemented to promote muscle hypertrophy [189]. Mechanisms involved in the hypertrophy of the muscle cell are thought to be partially associated with exercise-induced muscle damage (EIMD) and the consequent increases in the activity of satellite cells and inflammatory cells as well as the increase in the cell swelling [126,190]. Moreover, EIMD is associated to increases in muscle soreness, temporary muscle damage, intramuscular protein and passive muscle tension, and decreases in muscular strength and range of motion [191]. These responses to EIMD

will mediate various anabolic signalling pathways (e.g. Akt/mTOR pathway), that will ultimately increase protein synthesis [126,190]. As discussed, exposure to cold (i.e. cold recovery modalities) are likely to decrease this cascade of mechanisms and potentially decrease training adaptations. As reviewed by Peake et al. [192] studies performed in rats support the effects of cold therapies impairing muscle regeneration and decreasing muscle adaptation from training. In the few mechanistic clinical trials involving cold water therapies in human participants, results have consistently shown a decrease in muscle inflammation and anabolic signalling from cold exposure [88,174]. For this reason, during non-competition periods that involve training designed to increase muscle mass, it seems counter-productive to reduce the inflammatory response from exercise by exposing athletes to CWI or CWT [107]. It is however important to mention, that even during non-competition periods, different athletes will be exposed to different types of training according to individual needs [193]. For example, some athletes can be aiming to increase relative peak power output, and increases in lean muscle mass may be unwanted. In order to achieve maximal neural stimulus (e.g. peak power), it is important that each lift is performed maximally and therefore, sessions must be performed with athletes being in a non-fatigued state [45]. Given this, during these training phases, CWI or CWT can aid in training quality, therefore increasing the potential for training adaptations. For this reason, it is important to understand that the advice to completely avoid cold modalities within pre-season or other preparatory period, is not conclusive [107,175].

As with non-competition periods, during competition one should be mindful when deciding to include/exclude cold recovery modalities. For example in elite team sports such as rugby union, in-season resistance-training programs are designed to maintain the gains that occurred during preparation periods while attempting to further increases in strength, power and speed [6,194]. Given this, cold modalities can enhance recovery, allowing athletes to be more fresh on the subsequent training day and consequently increase the training quality (e.g. power output) [7,9]. Nevertheless, during some periods and/or with some athletes (see below; the *athlete goals* section), training programs can be designed for increases in muscle mass. Given the different intensities and aggression of the cold modalities used, one can also periodize the specific protocols (Table 3). In this example, during the first phase of pre-season, athletes refrained from using cold modalities as the goal established for these athletes during this phase of the season was to promote gains in muscle mass, and therefore, muscle damage, associated with an increase in DOMS, is desirable. During the second phase of the pre-season, resistance-training would targets increases in maximal strength, therefore, incorporating low intensity cold recovery modalities can enhance recovery, increasing training quality.

**Table 3.** Example of the resistance-training goals of a 9-week pre-season phase and recommendations for use of cold modalities.

<b>Period</b>	<b>Pre-season 1</b>					<b>Pre-season 2</b>			
<b>Goals</b>	<b>Muscle mass, strength, power, speed</b>					<b>Muscle mass, strength, Power, speed</b>			
<b>Weeks</b>	1	2	3	4	5	6	7	8	9
<b>Intensity of cold modalities</b>					<b>Unload</b>	+	+	++	++
<b>Example</b>						CWT: 2x (1 min cold:2 min hot)	CWT: 3x (1 min cold:2 min hot)	CWT: 2x (2 min cold:2 min hot)	CWI 1x 5 min cold

*Competitive level (density of the weekly schedule)*

The competitive level of an athlete is often associated with the training frequency and density of the training week, resulting in a reduction of the time to recovery. It is expected that athletes competing at a higher level (e.g. professional vs. amateur) have a greater number of weekly training sessions and training days when comparing to athletes competing at lower levels of competition [141]. Given the increase in the training density within the week, greater fatigue levels can be expected [141]. For example, in a previous study, it was observed that during a traditional in-season week, elite rugby athletes train up to ~11 h (~7 h of rugby training and ~4 h of gym training) and play one match, while amateur rugby athletes train for a total of ~6 h (~3 h of rugby training and ~3 h of gym training) and play one rugby match [141]. In addition, the demands of a match may differ between elite and amateur levels, increasing the time to recover. For example, in contact sports, different levels of muscle damage (e.g. creatine kinase levels) can be observed between elite and amateur levels [18,19,70]. Using rugby as an example, after an elite match, peak creatine kinase (CK) values ranged from 941 to 2194 U/l [18–20], while in amateur rugby matches, concentrations of CK ranged from 375 to 1081 U/l [7, 24, 55,70]. Therefore, it is not surprising that some researchers have observed significant increases in CK 120 hours following an elite rugby match [18], while in amateur rugby CK values returned to baseline 48 hours following a collegiate match [70]. These differences in the markers of muscle damage support the need for an individualized approach when implementing cold recovery modalities for different levels of athletes and for different sports (Table 4).

A critical factor is that if the frequency and intensity of the training sessions and match-play that an athlete is exposed to, allow for natural recovery (e.g. full recovery between sessions), the usage of cold modalities should be limited. In addition, fatigue, wellness and soreness levels are recommended to be monitored frequently to understand whether the athletes are fresh when they need to be (e.g. power training day or match-day). It is important to mention that even during the training week, one can implement cold modalities at different intensities, or not implement cold modalities at all, allowing for some residual fatigue and soreness to be present and therefore promoting adaptation to occur. In addition, using different protocols to diminish the monotony of recovery sessions may be appropriate and potentially increase the likelihood of a placebo effect [151]. As demonstrated in Table 4, on the day before and following the match, more intense cold modalities can be implemented to enhance recovery to increase performance in the match and to enhance recovery from the match.

**Table 4.** Example of a cold recovery scheme for elite and amateur team-sport athletes during an in-season week.

		Match day	Off	Day 1	Day 2	Day 3	Day 4	Day 5	Match Day
	Training load	Very High	Day off	Low to Moderate	High	Day off	Moderate to High	Low	Very High
Elite		Recovery from damage	Recover to adapt				Recover to perform		
	Intensity of cold modalities	+++			+		++	+++	
	Example	CWI: 2x5 min (11-15°C); full body			CWT: 3x (1 min cold:2 min hot); lower body		CWT: 3x (2 min cold:1 min hot); full body	CWI: 2x5 min (11-15°C); lower body	
	Training load	Very High	Day off	Low	Moderate to High	Day off	Moderate to Low	Low or day off	Very High
Amateur		Recovery from damage	Recover to adapt					Recover to perform	
	Intensity of cold modalities	+++					+	++	
	Example	CWI: 2x5 min (11-15°C); full body					CWT: 3x (1 min cold:2 min hot); lower body	CWT: 3x (2 min cold:1 min hot); lower body	

### *Goals of the athlete (long-term)*

The goal of an individual athlete is of utmost importance when selecting the use of cold modalities and deciding the intensity of the protocols to be implemented. For example, it is common to observe age-group athletes training within elite senior squads. Normally, these athletes have lower training ages and therefore have lower body weight and muscle mass in comparison to their elite counterparts. Using the example in Table 5, it might be reasonable to pursue further gains in muscle mass during the second pre-season phase and therefore, limit cold exposure in less experienced athletes. Similarly, if an athlete is less likely to be selected for some weeks and increases in muscle mass are desirable, practitioners may want to limit the use of cold modalities. The opposite can also occur whereby a more experienced and older athlete is regularly exposed to a greater training load (e.g. will be included in all drills within team-training) and match time. Therefore, aside from managing their training load, an increase in the intensity of the cold protocols can also be an option. An example for a training week in athletes with different training ages during the in-season can be observed in Table 5.

## **Conclusion**

Cold modalities are widely implemented for team-sport athletes and their effects in enhancing recovery from training and competition are well documented. Nevertheless, recent research suggests that implementing cold modalities such as cold water immersion can be detrimental for chronic training adaptations in athletes. Therefore, as with any training stimulus, cold recovery protocols must be carefully manipulated

by practitioners to each situation and individual in order to promote greater adaptations and subsequent performance. Understanding the intensity of the training, the density of the week, the athletes' individual goals and the requirements during the season will provide the rationale for the implementation and intensity of the cold modalities used.

# **CHAPTER SEVEN**

**Summary, Practical Applications, Limitations and Future Research**

## **Thesis Summary**

It has been widely demonstrated that rugby training and matches may lead to high levels of muscle damage and neuromuscular fatigue. As with other team-sports, running activity in rugby is intermittent, with bouts of high-speed running interspersed with low-intensity running. Moreover, rugby athletes are exposed to collision-based activities such as tackling, scrums, rucks and mauls. The combative and high-intensity intermittent nature of rugby leads to notable levels of fatigue and muscle damage [1, 3,130].

In **Chapter Four** we investigated the effects of rugby training and competition on different markers of fatigue. The two studies that we have published support previous research demonstrating that rugby training and competition lead to increases in muscle soreness and decreases in neuromuscular function. We have observed that obtaining the levels of soreness from different lower body muscle sites seems to be more sensitive than soreness obtained from a single question or from different upper body muscle sites [5,195].

Although monitoring muscle soreness in specific body parts is commonly used in endurance sports, this analysis has only recently been implemented in team sports (i.e. Australian-rules Football [121]). In a contact sport such as rugby, it is likely that damage arising from collision-based activities differs between muscle sites. Therefore, these findings provide important information for coaches as monitoring muscle soreness from specific lower-body sites seems to provide further information that can help elucidate the fatigue state and/or recovery of the athletes.

Another important finding from our studies was that although fatigue was accumulated throughout the training week, two recovery days were sufficient for fatigue levels to return to baseline [5,195]. While understanding the training load patterns is important to avoid undesirable fatigue states, it is important to mention that both studies were performed within the in-season period, where training loads are typically lower than in other periods; i.e. pre-season. Therefore, it is possible that when training load is higher, fatigue levels can be accumulated from week to week.

As demonstrated in **Chapter Four**, the fatigue levels from rugby lead to a temporary state of fatigue, where muscle function and performance is reduced. It is suggested that, if acute states of fatigue are extended over prolonged periods of time, it can lead to a state where athletes are chronically unable to respond and positively adapt to the imposed training loads. In order to expedite recovery, a number of effective recovery modalities should be implemented following rugby training and competition. With the implementation of these recovery modalities, sport scientists and coaches expect the athletes to be able to sustain training loads while avoiding the prolonged fatigue that may lead to an undesirable maladaptive state [107]. In **Chapter Two** we have provided the rationale for the implementation of recovery modalities to enhance recovery, while reviewing previously published research investigating the effects of different recovery modalities in rugby athletes. We have observed that CWI is the most investigated recovery modality within rugby literature [107]. This finding is in agreement with previous research demonstrating that CWI is the most implemented recovery modality after training sessions and matches in an elite rugby population [107]. Furthermore, the

findings from chapter three of this thesis demonstrate that CWI was one of the recovery modalities that was perceived as more effective and that was often implemented by elite rugby athletes [141].

In **Chapter Two**, we have revisited a topic that was recently raised in scientific literature about the acute and chronic effects of cold modalities, i.e. the acute benefits of implementing cold modalities for speeding up recovery as opposed to the chronic effects which may decrease the stress induced anabolic responses and consequently blunt muscle growth [88,142]. We have outlined that previous research investigating the effects of chronic exposure to cold recovery modalities lack transfer to the athletic population. Within other studies, the fact that the subjects in those studies were exposed to a low training frequency within the training week and low training intensities, limit the applicability of these findings to hard training elite rugby athletes [196]. To the best of our knowledge, there are no published studies examining the chronic effects of cold modalities in team-sport athletes whose training is structured such that they have limited time for recovery between training days. The findings from **Chapter Three** demonstrate that amateur rugby athletes implement significantly less cold modalities in comparison to elite athletes support the notion that implementing cold modalities should take into account the characteristics of the overall training schedule.

In **Chapter Five** we investigated the chronic effects of CWI within an elite rugby sample that was exposed to a dense and intense training schedule. In this study, the athletes were exposed to four resistance training sessions (two for lower body and two for upper body) designed to increase maximal strength and power, seven rugby field

sessions, two speed sessions, and four extra-conditioning sessions per week. Although the acute effects of CWI are widely demonstrated and were recently reviewed by us (**Chapter Two**), there is a lack of studies investigating the chronic effects of CWI on athletes exposed to training schedules that are structured in such way that the recovery period is insufficient to fully recover. The findings from **Chapter Five** demonstrated that CWI enhanced recovery in an elite sample of rugby athletes as demonstrated by the lower levels of muscle soreness and the maintenance of neuromuscular function in contrast to the control group throughout the study [196]. CWI also demonstrated to be beneficial at attenuating increases in IL-6 during the final stages of the study [196]. As widely discussed throughout this thesis, several studies have demonstrated the beneficial effects of CWI enhancing recovery and re-establishing muscle performance; while on the other hand, chronic use of CWI may interfere with anabolic pathways and consequently, muscle growth. Our findings provide important knowledge demonstrating that CWI may enhance recovery, allowing the athletes to perform at greater intensities, contributing to a greater overall adaptive stimulus [196].

In **Chapter Six**, the current knowledge on the different protocol characteristics and individual factors that may contribute to responses to cold modalities were evaluated. Practical recommendations based on external factors, such as the phase of the season, the density of the weekly schedule and the athletes' goals were presented, taking in to account the potential beneficial and harmful effects of cold modalities [154].

## **Practical Applications**

The following practical applications are based on the outcomes of seven studies within this thesis:

- In terms of recovery modalities implemented in rugby studies, cold modalities seem to have a beneficial effect on CK clearance, neuromuscular performance and DOMS. Compression garments provide enhanced recovery from DOMS, with a typical short-duration (i.e. 7 minutes) active recovery protocol being unlikely to provide additional benefits for recovery.
- Monitoring fatigue from a muscle soreness questionnaire seem to be an effective way to monitor readiness to train. Moreover, collecting data from different muscle sites and distinguishing between left and right sides of the body seems to be more sensitive than a single muscle soreness question and can provide important information for preventing and understanding injury mechanisms.
- CWI was demonstrated to have a beneficial effect on neuromuscular performance and lower body DOMS when rugby athletes are exposed to training schedules where recovery time is limited.
- Given that cold modalities (e.g. CWI or CWT) may affect hypertrophy signalling pathways, these techniques should be carefully implemented as they may limit adaptations in muscle size. When designing cold recovery protocols, practitioners need to consider the intensity of the training, the density of the week, the athletes' individual goals and the requirements during the season.

## **Limitations**

The findings and outcomes presented in the thesis have direct and practical outcomes for understanding the implementation of CWI in athletes. Whilst each experimental study acknowledged its own specific limitations, the overall limitations noted throughout each study are described below.

The research completed within this thesis was conducted in an elite rugby environment. Whilst using such a high level of athletes in their own training setting brings ecological validity to the studies, it also comes with some limitations (Figure 1). Ideally the sample size would be higher throughout our studies, however, we could not recruit additional participants and include them in the training setting of the rugby club where the participants from these studies were recruited. Furthermore, we were only able to select athletes that were exposed to homogeneous training loads and we were therefore required to remove those athletes who performed additional or modified training sessions. Moreover, the drop out was high in some studies as some athletes obtained injuries from training or competition. Another limitation was that the testing sessions had to suit the training schedule as it was not possible to change training around the research that was being conducted in this setting. For example, for **Study Five**, we wanted to measure other performance markers (e.g. speed, maximal strength, velocity during lower-body exercises), pre and post the three weeks of training but it was not possible as the post-intervention testing did not suit the training plan. The inclusion of muscle thickness measures to collect some information about the muscle were also contemplated, but again, the time and logistics required to collect the data meant that

this was not feasible. Moreover, inclusion of other measures of muscle size, using magnetic resonance imaging or muscle biopsies, would provide a more in-depth observation into the muscle adaptations to training. However, these methods are invasive and expensive, and therefore, were not applicable to research within the athletic population studied.

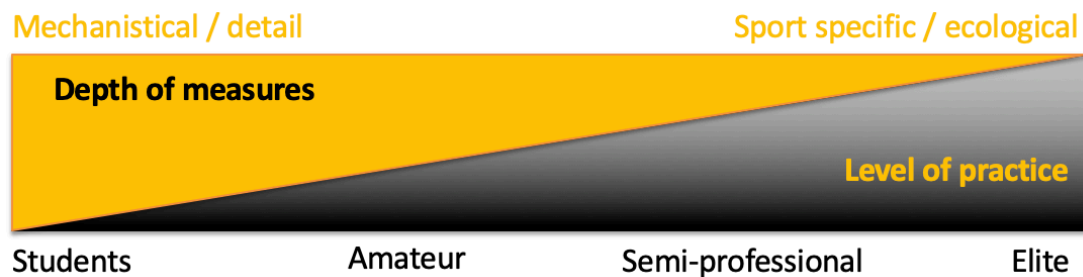


Figure 1. Schematic representation of the relationship between the depth of the measures and the level of practice.

One limitation of our research exploring the effects of CWI was the fact that there was no control for the placebo effect. The potential for the placebo effect is also a limitation of previous research investigating cold modalities, however, it is difficult to account for the placebo effect in CWI research. We could have opted to compare CWI with other recovery modalities, however this may not have allowed us to answer our overall question and would have required an even larger sample size.

### **Future Directions**

The present thesis has contributed to, and extended the body of knowledge in regards to the implementation of cold water immersion in team-sport athletes, particularly elite rugby union athletes. Recommendations for future research were presented in each of

the studies that were part of this thesis. In addition to the recommendations provided in each study, some future directions are described below.

Future research on cold recovery modalities should be conducted when the training characteristics (e.g. training weekly frequency, training sessions intensity and volume) do not allow for athletes to fully recover between training sessions. When participants can recover naturally and return to baseline measures, there is a limited rationale for the inclusion/investigation of cold modalities. Furthermore, more studies on cold recovery modalities should be conducted on highly trained athletes, due to their training characteristics, during different training phases and in different sport modalities.

The balance between the acute benefits of cold modalities enhancing performance when fatigue is accumulated over time (e.g. time between sessions is insufficient to recover) versus the potentially harmful effects on long-term muscle adaptations is still unknown. Future research should expose participants to high training loads/sessions (e.g. > 3 sessions per week), during prolonged periods of time (e.g. > 4 weeks) and monitor acute fatigue throughout the study while collecting pre- and post-markers of muscle size and contractile characteristics. Furthermore, these studies should also investigate the pre- to post-changes in relevant performance markers.

Although previous research has investigated the acute effects of cold water immersion on acute muscle anabolic responses, no other cold modalities (e.g. CWT, cryotherapy) or different protocols were compared. Following the rationale discussed in Study Seven, different cold modalities and protocols may have a different impact on recovery and

anabolic responses. Therefore, future studies should investigate and/or compare the effects of different cold modality protocols on acute recovery and anabolic responses.

In **Study Five**, we monitored training loads during rugby training (i.e. distance and high metabolic load distance), strength and power sessions (i.e. RPE) and off-feet conditioning sessions (i.e. RPE). We did not observe any differences between training loads in the CWI and control group. Although these measures have been previously implemented to monitor training load, they may lack sensitivity to monitor fatigue. Some other measures, such as: maximal velocity/acceleration during field training, velocity obtained on different exercises (e.g. back squat) during the strength and power sessions, or the time spent in different heart rate zones obtained during the off-feet sessions may provide additional information about the fatigue levels of athletes. Therefore, future research should include such measurements when investigating the effects of cold modalities on fatigue and readiness for training.

Finally, future research investigating the chronic effects of exposure to cold modalities should not fix/clamp the training volume and intensity. The expected outcome from implementing cold modalities is to allow for a greater training quality and/or quantity in the subsequent training sessions. If athletes perceive that they feel better recovered following CWI for example, they might be able to train at a higher intensity or at a greater volume in the next session. If training intensity is matched in the control and experimental groups, it does not allow researchers to answer this question.

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# APPENDICES

# **Appendix A - Wellness, muscle soreness and neuromuscular performance during a training week with increased volume in well-trained under-19 volleyball athletes.**

**Tavares F**, Simões M, Matos B, Smith TB, Driller M. Wellness, muscle soreness and neuromuscular performance during a training week in volleyball athletes. *J Sport Med Phys Fit.* 2017

## **Abstract**

**BACKGROUND:** The purpose of the current study is to analyse the acute effects of volleyball training and to compare the responses of different perceptual and neuromuscular measures to overall training load. **METHODS:** The training load, wellness, neuromuscular performance and perceptual measures of soreness of 13 highly-trained volleyball athletes ( $18 \pm 1$  years;  $187.1 \pm 7.0$  cm;  $84.3 \pm 10.3$  kg) representing the Portugal under-19 national team were monitored during a training week. Perceptual fatigue was obtained in the morning of every training day from a 5-item wellness questionnaire (sleep, soreness, mood, fatigue, stress) and a muscle soreness questionnaire surveying 9 different muscle sites from each side of the body. Neuromuscular performance was obtained from a countermovement jump (CMJ) on the morning of training day's 1, 2, 4 and 5. **RESULTS:** Significant differences ( $p < 0.05$ ) in CMJ were observed on Days 4 and 5 when compared to Baseline. Wellness items were affected by training, with the fatigue item and the total score being the most

affected. Muscle soreness from a single-question (wellness questionnaire) was significantly different on Days 4 and 5 in comparison to Baseline. Nevertheless, muscle soreness increased significantly from Day 2 until Day 5 in comparison to Baseline across various muscle sites and regions. **CONCLUSION:** Volleyball training elicits significant changes in physiological and perceptual measures of fatigue and muscle soreness, as evident from Day 2 until the last training day of the week. Muscle soreness scores obtained from different muscle sites are more sensitive to training load.

## **Introduction**

Volleyball is an intermittent team sport with high intensity efforts interspersed with periods of low intensity [197,198]. High intensity efforts in volleyball are characterized by jumps, lunges and locomotive actions (i.e. accelerations and decelerations) [197,198]. Depending on the playing position, a volleyball player can have a jumping frequency of up to 38 jumps per set, totalling ~145 jumps per game [197]. During the stretch shortening cycle and landing phases of a jump, some lower limb muscles will contract eccentrically in order to decelerate the movement of the body in the negative direction [199]. When compared to concentric muscle contractions, eccentric contractions are known to play the greatest role in muscle damage [67]. Therefore, post volleyball training or competition, considerable muscle damage is expected [163,200,201]. Due to the high values of muscle damage and subsequent muscle soreness caused by volleyball, acute fatigue is likely with performance being temporarily impaired [163]. At the elite level volleyball players typically train twice a day, for two or more days in a row [163]. Given the often short time to recover between

training days, an accumulated level of fatigue can be expected throughout the training week [163]. In addition, national teams play at least three games on consecutive days, in international volleyball competitions.

In a recent study, Freitas et al. [163] observed a decreased in neuromuscular performance and an increase in muscle soreness, biochemical markers of muscle damage and hormonal responses during one volleyball training week with professional athletes [163]. Furthermore, increases in perceptual and physiological markers of fatigue were previously observed in volleyball athletes after an intensified training block over an 11-day period [164]. For this reason, levels of fatigue need to be carefully monitored in order to avoid undesirable fatigue states in these athletes [32,202].

In order to monitor fatigue levels, sport scientists have utilised a range of tests [134, 163,195]. Within a diversity of tests, previous research has identified neuromuscular function tests and self-reported questionnaires as the most used tests between different sports [41]. Within different neuromuscular jump measures, flight time or jumping height obtained from a countermovement jump (CMJ) performed on a contact mat are commonly utilized [31,163]. With regard to the self-reported questionnaires, the McLean et al. questionnaire has been validated [8] and previously used as a practical tool to monitor fatigue [8,31]. Amongst the different perceptual measures to monitor fatigue, muscle soreness has been identified as the most frequently used [41]. In addition, increases in muscle soreness have been previously observed after volleyball training, [163] which suggests structural damage in the skeletal muscle and consequent disorganisation of the myofilament alignment [120,128]. Furthermore, muscle damage is associated with loss of neuromuscular function [120,128]. Although monitoring

muscle soreness in specific body parts is commonly used in endurance sports, this analysis has only recently been implemented in contact team sports (i.e. Australian-rules Football [121]; rugby union [195]). Given the importance of tracking muscle soreness for high performance sports and athletes, [131] it might be useful to include measures of muscle soreness from different muscle groups as part of the overall wellness monitoring procedure [121,122,195]. Given the high occurrence of jumping actions in volleyball, the effective monitoring of muscle soreness may contribute to injury prevention [197,198,203,204].

Although previous research has explored the acute effect of training and competition on fatigue in different sports (rugby [195], soccer [134] and basketball [136]), relevant literature on volleyball is scarce and limited to elite athletes [163] or biochemical markers [200,201]. This is somewhat surprising given the high rate of overuse injuries occurring in volleyball [203,204]. Moreover, although the usage of specific muscle-site soreness questionnaires has been previously recommended [122] and utilized in contact sports [121,195], to our knowledge, there are no studies that have investigated muscle soreness responses to volleyball training. Therefore, the purpose of the current study was to analyse the acute effects of volleyball training and to compare the responses of different perceptual and neuromuscular measures to overall training load.

## **Methods**

### *Participants*

Thirteen highly-trained volleyball athletes ( $18 \pm 1$  years;  $187.1 \pm 7.0$  cm;  $84.3 \pm 10.3$  kg) representing the Portugal under-19 national team volunteered to participate in the current study. Data from training load, neuromuscular performance, perceived muscle soreness and perceived wellness were collected during one week of a training camp. Ethical approval was given by the Technical-Scientific Council of the University and written informed consent was obtained from all athletes.

### *Procedures*

Measures of perceptual wellness and muscle soreness were collected on five days (Day 1 to Day 5) during one week of a National training camp. Neuromuscular jump performance was collected on Days 1, 2 4 and 5 (Table 1). During this period, all training session loads (field and gym-based sessions) from all participants were obtained from rating of perceived exertion (RPE) scores [122].

The training program consisted of four resistance training sessions (two for lower body and two for upper body) designed to increase power while maintaining maximum strength (i.e. six exercises of three sets of six to eight reps with varied loads [189]) and eight volleyball court sessions (Table 1).

**Table 1.** Training program during the period of the study. Resistance training, conditioning and technical-tactical duration (minutes), and qualitative intensity or type of training are described. Load data from resistance training and volleyball practice (arbitrary units: sRPE x duration) are represented as mean  $\pm$  SD. All fatigue monitoring data collection occurred before the first session of the day.

<b>Training period</b>					
	Day 1	Day 2	Day 3	Day 4	Day 5
Before	J+Q	J+Q	Q	J+Q	J+Q
Morning	<b>Gym session (UB</b> S+P: 40'; 127 AU)	<b>Gym session (LB</b> S+P: 40'; 182 AU)		<b>Gym session (UB</b> P: 40'; 167 AU)	<b>Gym session (LB</b> P: 40'; 175 AU)
	<b>VB (90'; 311 AU)</b>	<b>VB (180'; 704 AU)</b>		<b>VB (180'; 867 AU)</b>	<b>VB (180'; 769 AU)</b>
Afternoon	<b>VB (120'; 393 AU)</b>	<b>VB (80'; 269 AU)</b>	<b>VB (150'; 614 AU)</b>	<b>VB (180'; 756 AU)</b>	
Volleyball (AU)	704 $\pm$ 194	973 $\pm$ 253	614 $\pm$ 246	1623 $\pm$ 580	769 $\pm$ 302
Weights load (sets x reps)	127 $\pm$ 24	182 $\pm$ 60		167 $\pm$ 39	175 $\pm$ 45

Arbitrary units (AU); Jumping performance (J); Lower body (LB); Max strength (S); Power (P); Upper body (UB); Volleyball practice (VB); Wellness and soreness questionnaires (Q).

### *Perceptual measures*

A wellness questionnaire was completed by all participants each morning of the training week (Days 1 to 5). This questionnaire was comprised of five questions and was designed to measure the perceived fatigue (fatigue WQ), general muscle soreness (soreness WQ), sleep quality, stress levels, and mood state of athletes using a 5-point Likert scale with 0.5-point increments [5,8]. In order to gain a more detailed understanding of muscle soreness, a second questionnaire using the same 5-point Likert scale with 0.5-point increments was also used [5]. This questionnaire assesses the soreness of nine specific muscle sites (quadriceps, gluteus, hamstrings, calves, groin,

lower back, upper back, shoulder, chest) from left and right sides. A measure of lower body muscle soreness (soreness LB) was calculated from the sum of the left and right quadricep, groin, calf, hamstring and gluteus muscle soreness ratings. A measure of upper body muscle soreness (soreness UB) was calculated from the sum of the left and right shoulder, chest, upper back and lower back) muscle soreness. The whole-body soreness (soreness WB) was calculated from the sum of all muscles/muscle regions. Both of these questionnaires have been previously used in team-sports [5,8]. In both questionnaires, a higher score corresponds to a positive wellness state or less muscle soreness.

*Neuromuscular performance (Countermovement Jump Peak Force)*

In order to monitor neuromuscular fatigue, jump height was measured during a countermovement jump (CMJ) test performed each morning on Days 1, 2, 4 and 5 (Table 1). Following a standardized warm-up composed of dynamic stretches and movements (e.g. one-leg standing knee flexion, bodyweight squats, bodyweight CMJ) athletes performed three CMJ on a 42-cm contact mat (Chronojump-Boscosystem, Barcelona, Spain) with five seconds seconds of interval between each jump. The mat was connected to a microcomputer (Chronopic 3, Chronojump-Boscosystem, Barcelona, Spain), which was then connected to a PC and software (Chronojump-Boscosystem Software, Spain) through a USB port. The jumping height was estimated by means of flight time through a standardized kinematic equation  $= t^2 \cdot g / 8$ , where  $g$  is the gravity acceleration ( $9.81 \text{ m/s}^2$ ) [205]. Each trial started with the athletes standing on the contact mat with their knees fully extended and the hands on hips to eliminate the influence of arm swing. Athletes were then instructed to descend to a self-selected

countermovement depth and to jump as high and quickly as possible. The best trial, determined by jump height, was retained for later analysis. Jump height calculated with this contact mat system was previously demonstrated to be both valid and reliable [206].

### *Training load*

The individual training RPE of each resistance training and volleyball training session was obtained between 15 and 30 minutes after the completion of the session [138]. The training load was then calculated as the product of the individual session RPE (sRPE) and the duration of the session using the following formula: Training load = sRPE (1-10) x duration of the session (min) [122].

### *Statistical Analysis*

The data collected was analyzed using a Statistical Package for Social Sciences (Version 22.0, SPSS Inc., IBM, Chicago). The Shapiro-Wilk test was performed to assess normality for each variable. A paired samples T-test was used to analyze differences between training days and Baseline (Day 1). Whenever the condition of normality of a variable was rejected or the values were presented on an ordinal scale (wellness and body soreness questionnaires) a Wilcoxon test was utilized. A Wilcoxon test was also used to compare the differences between left and right sides for soreness of the different muscles sites. A significance level of  $p < 0.05$  was implemented for all statistical tests.

In addition, the standardised change in the mean for CMJ, soreness and the wellness questionnaire compared to Baseline for each day was determined and expressed as effect sizes (Cohen's  $d$ ) by dividing the average Baseline between-subject standard

deviation (SD) for that variable. Magnitudes of the standardised effects for CMJ and total scores of soreness were interpreted using thresholds of 0.2, 0.6, 1.2, 2 and 4 for *small, moderate, large, very large and extremely large* respectively.[109] An effect size of < 0.2 was considered *trivial* [109]. Where the 90% confidence limits overlapped *small* positive and negative values, the effect was deemed *unclear*.

## Results

No significant differences ( $p < 0.05$ ) were found on any day between left and right sides for muscle soreness across each muscle site. Therefore, the average of left and right sides was calculated and used for analysis (Table 2).

**Table 2.** Mean  $\pm$  SD soreness for the different muscles/muscle regions, wellness questionnaire parameters and CMJ performance (cm)

	Day 1	Day 2	Day 3	Day 4	Day 5
CMJ (cm)	40.2 $\pm$ 7.6	39.2 $\pm$ 7.2		36.4 $\pm$ 5.6 <sup>#*</sup>	37.6 $\pm$ 6.3 <sup>#</sup>
Quadriceps	4.4 $\pm$ 1.0	4.2 $\pm$ 1.1	3.8 $\pm$ 1.1	3.5 $\pm$ 1.2 <sup>^</sup>	3.1 $\pm$ 1.4 <sup>^*</sup>
Groin	4.7 $\pm$ 0.6	4.8 $\pm$ 0.5	4.4 $\pm$ 0.6	4.5 $\pm$ 0.8 <sup>#</sup>	4.2 $\pm$ 1.3 <sup>^</sup>
Chest	4.8 $\pm$ 0.5	4.6 $\pm$ 0.7	4.0 $\pm$ 1.0 <sup>&amp;</sup>	4.3 $\pm$ 1.0 <sup>^</sup>	4.4 $\pm$ 1.1 <sup>^</sup>
Shoulder	4.1 $\pm$ 1.2	3.6 $\pm$ 1.3 <sup>#*</sup>	3.4 $\pm$ 1.0 <sup>^*</sup>	3.3 $\pm$ 1.0 <sup>^*</sup>	3.9 $\pm$ 1.4
Calves	4.8 $\pm$ 0.4	4.6 $\pm$ 0.8 <sup>^</sup>	3.8 $\pm$ 1.1 <sup>%*</sup>	3.6 $\pm$ 1.1 <sup>%*</sup>	4.0 $\pm$ 1.3 <sup>&amp;</sup>
Hamstrings	4.7 $\pm$ 0.5	4.5 $\pm$ 1.0 <sup>#</sup>	3.4 $\pm$ 0.9 <sup>%*</sup>	3.5 $\pm$ 1.2 <sup>%*</sup>	3.6 $\pm$ 1.4 <sup>&amp;*</sup>
Gluteus	4.7 $\pm$ 0.5	4.7 $\pm$ 0.7	4.0 $\pm$ 1.1 <sup>&amp;</sup>	4.3 $\pm$ 1.1	4.4 $\pm$ 0.9 <sup>^</sup>
Lower Back	4.5 $\pm$ 0.9	4.4 $\pm$ 0.7	4.0 $\pm$ 0.9	4.3 $\pm$ 0.9	4.4 $\pm$ 1.2
Upper Back	4.6 $\pm$ 0.7	3.8 $\pm$ 1.5 <sup>&amp;</sup>	3.2 $\pm$ 1.2 <sup>%*</sup>	3.7 $\pm$ 1.3 <sup>&amp;*</sup>	3.8 $\pm$ 1.5 <sup>&amp;</sup>
Upper body	4.7 $\pm$ 0.5	4.5 $\pm$ 0.7 <sup>#</sup>	3.8 $\pm$ 0.7 <sup>&amp;*</sup>	4.0 $\pm$ 0.8 <sup>&amp;*</sup>	4.0 $\pm$ 0.9 <sup>&amp;*</sup>
Lower Body	4.5 $\pm$ 0.6	4.1 $\pm$ 0.9 <sup>^*</sup>	3.6 $\pm$ 0.7 <sup>&amp;*</sup>	4.0 $\pm$ 0.8 <sup>*</sup>	4.0 $\pm$ 0.9 <sup>^</sup>
Whole Body	4.6 $\pm$ 0.5	4.3 $\pm$ 0.9 <sup>^*</sup>	3.7 $\pm$ 0.7 <sup>&amp;*</sup>	3.8 $\pm$ 0.7 <sup>&amp;*</sup>	3.9 $\pm$ 0.8 <sup>^*</sup>

Wellness Questionnaire (AU)	Fatigue	4.4 ± 0.9	3.8 ± 0.6 <sup>^</sup>	2.9 ± 0.9 <sup>&amp;*</sup>	2.3 ± 0.7 <sup>%*</sup>	1.9 ± 0.8 <sup>%*</sup>
	Sleep	3.5 ± 0.7	4.1 ± 0.5 <sup>^</sup>	3.8 ± 0.7	3.5 ± 0.9	3.9 ± 0.7 <sup>^</sup>
	Soreness	3.7 ± 0.8	3.6 ± 0.9 <sup>#</sup>	3.1 ± 0.9 <sup>^</sup>	2.6 ± 0.7 <sup>&amp;*</sup>	2.0 ± 0.6 <sup>%*</sup>
	Stress	4.7 ± 0.5	4.6 ± 0.5 <sup>#</sup>	4.6 ± 0.7	4.2 ± 0.4 <sup>^*</sup>	4.2 ± 0.6 <sup>^</sup>
	Mood	4.7 ± 0.5	4.8 ± 0.4	4.6 ± 0.5	4.2 ± 0.6 <sup>^*</sup>	4.6 ± 0.7
	Total	21.0 ± 2.0	20.8 ± 1.8	19.0 ± 2.5 <sup>^*</sup>	16.8 ± 1.0 <sup>&amp;*</sup>	16.6 ± 1.9 <sup>%*</sup>

\*Significant difference ( $p < 0.05$ ) from Baseline (day 1).

#*Small* effect sizes in comparison to Baseline (day 1).

<sup>^</sup>*Moderate* effect sizes in comparison to Baseline (day 1).

<sup>&</sup>*Large* effect sizes in comparison to Baseline (day 1).

<sup>%</sup>*Very Large* effect sizes in comparison to Baseline (day 1).

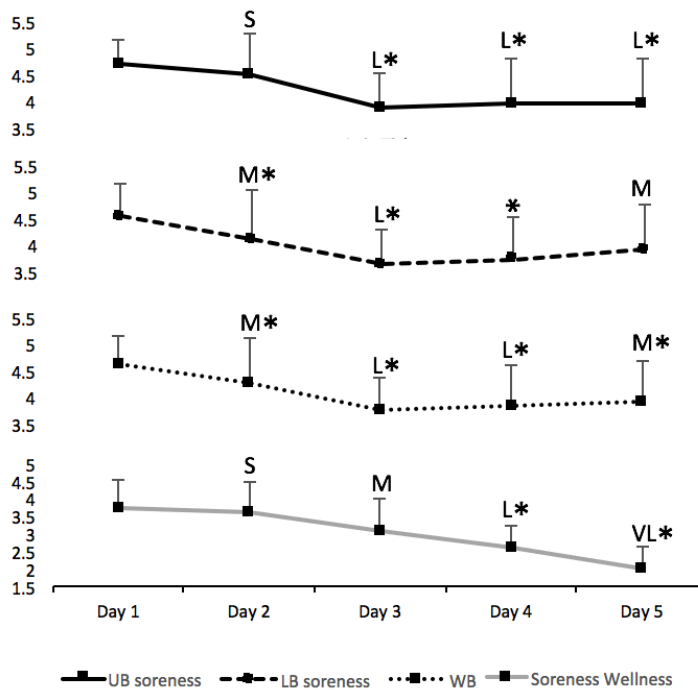
The wellness scores, soreness scores and CMJ performance for each day was compared to Baseline (Table 2). In general, a notable decrease in the wellness scores and increase in muscle soreness and fatigue throughout the week was observed. Countermovement jump performance decreased during the training week, with significant changes observed on Day 4 and *small* effect sizes observed on both Days 4 and Day 5 when compared to Baseline.

With the exception of sleep, all other wellness items were affected by training (Table 2). In particular, on Day 4 there was a more pronounced difference in all item scores (except sleep). The fatigue item and the total score were the most affected, with significant differences being observed on Days 3, 4 and 5. These changes were associated with *moderate* to *very large* effect sizes.

An increase in muscle soreness in comparison to Day 1 was observed from Day 2 until Day 5 across various muscle sites and regions (i.e. UB, LB and WB soreness). In particular, shoulders, calves, quadriceps, hamstrings and upper back muscles were

significantly sorer during the training week, associated with *small* to *very large* effect sizes.

**Figure 1.** Mean  $\pm$  SD soreness for the upper body (UB), lower body (LB) and whole body (WB) soreness from soreness questionnaire and total soreness from wellness questionnaire. \*Significant differences ( $p < 0.05$ ) from Baseline. *Small* (S), *Moderate* (M), *Large* (L) and *Very Large* (%VL) effect sizes in comparison to Baseline.



Significant differences to Baseline were found from Day 3 to Day 5 for UB soreness, Day 2 to Day 4 for LB soreness and Day 2 to Day 5 for WB soreness (Table 2; Figure 1). When the soreness was obtained from a single question (i.e. soreness from the wellness questionnaire), significant differences were only observed for Days 4 and 5 (Table 2; Figure 1).

## Discussion

The main finding of the current study is that volleyball training induces increases in muscle soreness, and decreases in the perception of wellbeing and neuromuscular performance (Table 3). These results are supported by previous research that have reported an increase in fatigue, soreness and muscle damage in elite volleyball training [163] and competition [200,201]. Nevertheless, literature investigating the effects of volleyball on fatigue is limited to elite senior athletes. Understanding the fatigue levels that a broader athletic population is exposed to is essential for avoiding undesirable fatigue states while promoting a training stimulus that leads to physiological adaptations [32, 164,202] and to understand the possible causes of overuse injuries [203,204].

The results from the present study demonstrate an increase in muscle soreness, particularly in shoulders, calves, quadriceps, hamstrings and upper back muscles. Not surprisingly, the two most commonly observed overuse injuries in volleyball occur in joints that involve these muscle regions [203]. Although increases in muscle soreness can be observed on Days 2 and 5, the scores were more pronounced during the middle of the week (e.g. day 3, 4). On Days 1 and 2 athletes were exposed essentially to high strength loads (e.g. ~80-100% 1-RM) while on Days 4 and 5 athletes trained with low lifting-loads and high-velocity (e.g. 0-30% 1-RM) (Table 1). The higher strength training lifting-loads are associated with a greater muscle disruption [126] and consequently, higher levels of muscle soreness [128]. Therefore, the greatest level of muscle soreness observed on Days 3 and 4 can be partially justified by the different resistance-training methods utilized, even with similar perceived exertions (sRPE).

Wellness questionnaire items were also affected by training, with the exception of sleep (Table 2), with greater changes occurring on Day 4. The fatigue item and the total score were the most affected, with significant differences being observed on Days 3, 4 and 5. These changes were evidenced by *moderate* to *very large* effect sizes. According to the soreness item from the wellness questionnaire, athletes were significantly more sore on Days 4 and 5 in comparison to Baseline (Table 2; Figure 1). Increases in muscle soreness in response to volleyball training have been recently reported [163]. Similar to the findings of the present study, Freitas et al. [163] also observed an increase in muscle soreness at the end of the training week with no significant changes occurring during the first two days when using a single question to detect muscle soreness. A greater number of significant changes for muscle soreness when obtained from the average of different muscle groups (i.e. Days 3 to 5 for UB soreness, Days 2 to 4 for LB soreness and Days 2 to 5 in WB soreness) was observed in comparison to a single question (from the wellness questionnaire). For this reason, the findings from the present study reinforce previous research suggestions on the importance of obtaining muscle soreness from different muscle sites [5, 121,122, 131,195].

Similar to the results on perceptual measures in the current study, CMJ performance was also significantly decreased on Day 4 (Table 2). In addition, *small* effect sizes were observed on Days 4 and 5. These results are not surprising given the association between muscle damage and the loss of neuromuscular function [120,128]. The research from Freitas et al. [163] partially support our findings as the authors reported non-significant, *small* to *large* changes from baseline during a training week. Nevertheless, in their study, neuromuscular performance was more pronounced on Day

2 (*large* ES) in comparison to Days 2 to Day 6 (*small* effect sizes), suggesting that jump performance may not follow the exact same timeline as muscle soreness.

The measures of muscle soreness in the current study showed similar trends to measures of physiological and perceptual well-being. However, as previously reported, the sum of various lower body muscle sites was demonstrated to be more sensitive than a single question about soreness [5,195]. In a sport where the technical movements are frequently repeated (e.g. volleyball spike), occurrence of overuse injuries are likely to occur [203]. Collecting individual soreness data from different muscle sites will provide important information in order to manipulate training loads. For example, while some athletes may tolerate a higher volume (involving a joint) on the same training day (e.g. UB strength and power training and volleyball spike training), others may respond better to splitting these two training sessions over two separate days. For the aforementioned reasons, data from the present study suggest that a questionnaire that monitor different muscle sites soreness should to be included as part of the fatigue monitoring protocol used by medical and coaching staff.

In conclusion, volleyball training in highly-trained non-professional athletes elicit significant changes in physiological and perceptual measures of fatigue and muscle soreness. These changes were evident from Day 2 until the last training day of the week (Day 5). Although transient states of fatigue are expected and desirable in order to promote adaptations to training, future research should explore if fatigue is still detected after the recovery period during training microcycles (e.g. two-days). If that is the case, it can indicate a state of accumulated fatigue [164] that can lead to a non-functional overreaching state [32]. Muscle soreness scores differ when obtained from

a single question or from different muscle sites, suggesting that muscle soreness should be measured from specific muscle sites.

# **Appendix B - Effect of cold water immersion on elbow flexors muscle thickness after resistance training**

Matos, F., Neves, E. B., Rosa, C., Reis, V. M., Saavedra, F., Silva, S., **Tavares, F.**, Vilaça-Alves, J. (2018). Effect of cold-water immersion on elbow flexors muscle thickness after resistance training. *The Journal of Strength & Conditioning Research*, 32(3), 756-763.

## **Abstract**

Cold Water Immersion (CWI) is commonly applied in order to speed up the recovery process after exercise. Muscle damage may induce a performance reduction, consequence of the intramuscular pressure induced by the muscular swelling. We aimed to understand the CWI effects on muscle thickness (MT) behaviour of the elbow flexors after a resistance training (RT). Eleven males were submitted to a RT, performed in two different weeks. In one of the weeks, subjects experienced a passive recovery. In the other, subjects were submitted to a CWI. Ultrasound (US) images were taken pre-, post-, as well as 24h, 48h and 72h post-exercise, to evaluate the MT. MT in both exercise (EA) and control (CA) arms was significantly higher 48h and 72h post-exercise when subjects experimented a passive recovery compared with the CWI ( $p=0.029$ ,  $p=0.028$  and  $p=0.009$ ,  $p=0.001$ , 48h, 72h, EA and CA, respectively). When each arm was analysed with or without use CWI individually, significantly higher MT was observed in the EA with CWI: pre-exercise in relation to 72h post-exercise ( $p=0.042$ ); and post-exercise in relation to the other measurements ( $p=0.003$ ,  $p=0.003$ ,

p=0.038 and p<0.0001, pre-exercise and 24h, 48h, 72h post-exercise, respectively). The evaluation of MT by US provides evidence that CWI after RT (and 24h post-exercise) may reduce muscle swelling in the post-exercise days when compared with a passive recovery. Seems to be a paradox between the use of CWI for an acute reduction of muscle swelling to facilitate recovery and the potential negative effects on muscle hypertrophy.

**Keywords:** DOMS; Swelling; Cryotherapy; Muscle Damage; Muscle recovery.

## A. INTRODUCTION

Exercise, by itself, induces natural damage to the muscle-skeletal tissue, causing various responses, proportional to the duration, strength and muscle mass recruited. The body's recovery to muscle damage caused by exercise will depend on the course of time, the severity of pain and the level of muscular dysfunction [207,208].

Athletes, coaches, individuals exercising for recreation and practitioners working with clinical populations often seek ancillary strategies to enhance the muscular recovery process. In sports medicine, many post-exercise recovery techniques have been investigated in order to find methods to reduce the secondary symptoms of the magnitude of damage caused by exercise, and accelerate the recovery process in order to help regular individuals and athletes to maintain the required workload during subsequent training sessions while reducing the risk of injury [209]

Several methods of cryotherapy are becoming increasingly popular as a tool to improve muscular recovery following exercise. In fact, the physiological responses to these methods are still poorly understood [210,211]. The literature has shown that the magnitude of tissue temperature change is correlated positively with cryotherapy methods that undergo a phase change [212], have a higher thermal gradient [213], long-term through time [214] or are applied over a larger surface area [215].

Cold-water immersion (CWI), which involves immersing the body or body parts in water at temperatures below 15°C for periods of between 3 and 20 minutes, are commonly applied to speed up the muscular recovery process [211]. However, despite the development of clinical guidelines, the literature is inconclusive regarding its

applicability. There is no consensus on the effectiveness of these methods, continuing with ambiguous protocols, and without optimal application times [88,210].

Bleakley et al [210] performed a systematic review aiming to understand the effectiveness of CWI protocols in order to prevent and treat the muscle-skeletal damage caused by exercise, published in *The Cochrane Library*. A total of 17 studies, published between 1998 and 2009, were included in this review. Among the 17 studies included in this review, there were only 5 that studied the effects of CWI after a resistance training (RT) protocol [216–220] and of these 5 studies, there was only one that compared the effects of CWI with a passive recovery [220].

Therefore, Bleakley et al. [210] concluded that there was no consensus regarding the effects of CWI protocols on muscular recovery due to various and poor methodologies applied. To the date of this writing, only 4 more studies involving RT and CWI protocols can be found [88,221–223].

The application of cryotherapy methods, as well as CWI, aims to attenuate secondary effects such as pain, discomfort, oedema and muscular dysfunction. These secondary effects are common after a resistance training programme to achieve muscular hypertrophy and usually achieves a peak between 24 and 72 hours post-exercise [212,216]. Delayed-onset muscle soreness (DOMS) is the usual term used to define this pain and muscular dysfunction [207].

DOMS may induce a performance reduction, disturb the muscular position sense and cause a decrease in reaction time [224]. Usually, these secondary effects are consequences of intramuscular pressure, induced by muscular swelling, in response to the muscular aggression [225]. The quantity of muscle mass volume can be assessed

by the measure of muscle thickness (MT), which can be evaluated by ultrasonography [226]

Thus, we aimed to understand the CWI effects on muscle thickness behaviour of the elbow flexors after a resistance training protocol.

## B. METHODS

### *Experimental approach to the problem.*

At the first and second sessions, a 1RM (Maximum Repetition) Test was applied [227] for *biceps curl* (with forearm supination) and *biceps curl hammer* (without forearm supination) in order to infer the workload for each subject. Then, 72h later, the 1RM re-test was performed to achieve reliable workload data.

The experimental trial was divided into two weeks, which differ only in the muscular recovery therapies applied. On both weeks, the subjects performed the same RT protocol for the Exercised Arm (EA). The other arm did not perform any RT protocol so could be used as a Control Arm (CA). The difference between the weeks was the recovery therapy applied: 1) CWI; and 2) Passive Recovery.

### *Subjects*

Before providing their written informed consent, all participants were informed of the requirements and potential risks of the studies. The experimental procedures adhered to the standards set by the latest revision of the *Declaration of Helsinki (2013)*, for ethics in research with human beings. This study was a randomised controlled trial in which physically active men (n=11), who were familiar with the biceps curl exercise, and who had been RT 2 to 3 times a week for the previous 6 months, volunteered to

participate in a 2 week RT and CWI protocol. Experimental procedures and risks were explained to the participants before they provided their informed consent to take part in the study. The inclusion criteria were: male gender, Caucasian ethnicity and apparently healthy. To define the inclusion criteria, the subjects completed the Par-Q test questionnaires (ACSM, 2007), an anamnesis specifically designed according the requirements of assessment methods involved in this investigation. The characteristics of the participants in this study are described in Table 1.

**Table 1.** – Descriptive characteristics of subjects

	<b>n</b>	<b>mín</b>	<b>máx</b>	<b>Mean ± SD</b>
<b>Age</b>	11	18	33	20,50±3,92
<b>BH</b> (Body Height, cm)	11	164	180	1,76±4,55
<b>BM</b> (Body Mass, kg)	11	60,6	78,0	70,4±3,69
<b>BF</b> (Body Fat, %)	11	3,7	16,5	9,4±3,30

### ***Procedures***

All trials started at 10 a.m. The participants were informed to eat similar food during the experiment trials, asked to avoid consuming stimulants, alcohol, tobacco, antioxidants and nutritional supplementation for 24h preceding all trials, and informed not to do any strength exercise for 48h prior to each trial.

### **Resistance Training Protocol**

Subjects were submitted to the same RT protocol in both weeks, under the same conditions: Five sets of biceps curl (with forearm supination) and hammer biceps curl (without forearm supination), organised in *Bi-set*, at 70% of 1RM [228]. The rest period established was 1min 30sec. The movement cadence was 60 bpm (beats per minute), monitored by a metronome (Dolphin<sup>®</sup> Dp31g).

### **Recovery Therapy protocol**

1) In one of the experimental weeks, CWI was the cryotherapy protocol implemented. The EA was immersed for 20 minutes in a container filled with ice and water at a temperature between 5°C and 10°C, immediately post-exercise and 24h after. As a matter of safety, the hand was not immersed to avoid the adverse effects of low temperatures to the body extremities [229].

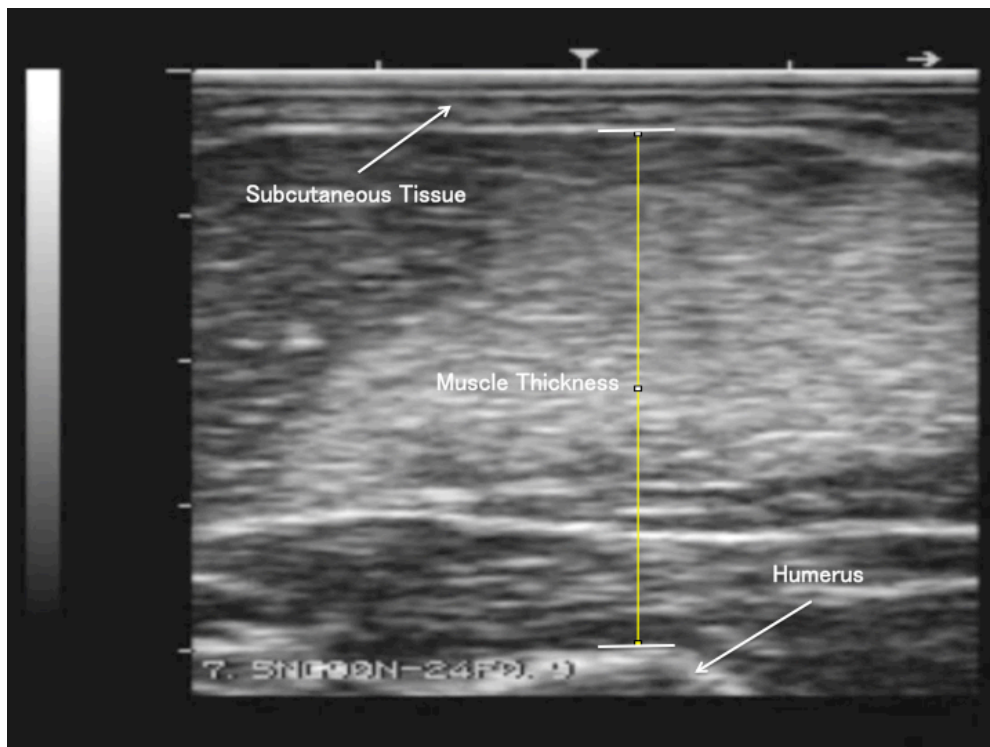
The water in the container was monitored with a Thermocouple DFT-M-700 (Shinko Technos Co. Osaka, Japan). The whole treatment process was carefully monitored for greater control of the water temperature and the subjects' safety. The addition of ice was made according to the requirements caused by the heat balance, in order to keep the temperature as constant as possible. 2) On the other week, there was no recovery therapy applied (Passive Recovery).

### **Muscle Thickness Assessment**

MT was obtained using an ultrasound (US) Aloka<sup>®</sup> SSD 500V (Toquio, Japan) with an electronic linear transducer of 7.5 MHz (UST-5512U-7.5, 38 mm, Aloka<sup>®</sup>) wave frequency, used for a transverse scan. Elbow flexors MT (Biceps Brachii; Brachialis) were measured pre- and immediately post-exercise, as well as 24, 48 and

72 hours post-exercise. US images were kept on video. In order to standardise the measurements, US images were acquired at 60% of the distance between the posterior ridge of the acromion and the olecranon of the arms, while the subject was seated with his arms relaxed on their respective sides [230]. Elbow flexors MT were considered as the distance between the interfaces of the muscle tissue, from the subcutaneous tissue to the humerus bone (Figure 1). US settings were kept unchanged throughout the image acquisitions.

MT analysis was exported to a personal computer and analysed using open-source *ImageJ*<sup>®</sup> software version 1.37 (National institute of health, USA) as shown in figure 1 [231].



**Figure 1** – US image of the Elbow Flexors MT, considered as the distance between the interfaces of the muscle tissue, from the subcutaneous fat to the bone.

## **Skin Temperature Assessment**

Thermal images were taken pre- and immediately post- as well as 24, 48 and 72 hours post-exercise. Furthermore, thermal images were taken immediately after the CWI protocol. Images were acquired during morning (10:00 am).

The skin surface temperature assessment was performed in a room with a conditioned environment within a range of 22°C to 24°C, monitored by a digital thermometer (Elecs HTC-2). Thermal images were captured using a Thermographic Camera Ti32 from Fluke® Technologies (Mumbai, India).

The camera was positioned on a tripod  $\pm 1$  metre above the ground and  $\pm 1$  metre from the subject. There was a non-reflecting background behind the subject.

Thermal images were analysed using regions of interest (ROI), which include: 1) 60% of the distance between the posterior ridge of the acromion and the olecranon of the arm; 2) the xiphoid process as a reference of the central body temperature. These regions were accessed with the computer software *SmartView® Thermal Imaging Analysis* (Fluke® Technologies, Mumbai, India), which provided us with the average and mean temperatures from each analysed ROI [229]

## ***Statistical Analysis***

The results are shown with the average  $\pm$  standard deviation. For comparisons between arms (exercise and control) and between the immersion with and without the bath for each time point analysed were determined using a T-test for independent variables. An ANOVA for repeated measures analysed was utilised with the following models: five moments (pre-exercise, post-exercise, and 24h, 48h and 72h post-

exercise) x two sessions (with and without immersion bath) x two arms (exercise and control). A Bonferroni post hoc test was used to identify differences between the moments, sessions and arms. All data analysed with the ANOVA were tested for assumptions of normality, homogeneity and sphericity. The level of significance was established at 5%. The statistical analyses were conducted using SPSS 22.0 (SPSS, Inc., Chicago, IL, USA).

### C. RESULTS

On average, subjects were submitted to a cold-water immersion with a temperature of  $8.3 \pm 0.76$ . Table 2 shows the skin temperature reductions caused by the CWI in the elbow flexors of the arm submitted to the RT protocol.

**Table 2.** Mean  $\pm$  standard deviation  $T_{sk}$  of the elbow flexors after the CWI protocol.

<b>CWI application</b>	<b>Pre-<math>T_{sk}</math></b>	<b>Post-<math>T_{sk}</math></b>	<b>Post-Pre</b>	<b>Post-Pre (%)</b>
Immediately PostE	$34.60 \pm 0.62$ °C	$20.37 \pm 2.74$ °C	$14.23 \pm 2.78$ °C	41.09 %
24 hours PostE	$35.15 \pm 1.08$ °C	$21.11 \pm 2.17$ °C	$14.04 \pm 1.99$ °C	39.94 %

**CWI** – cold water immersion; **PostE** – Post-exercise;  **$T_{sk}$**  – Skin Temperature

When CWI was applied immediately post-exercise we can observe  $T_{sk}$  reductions around  $14.00^{\circ}\text{C}$  ( $\pm 2.78$ ), in the elbow flexors ROI. Similarly, when CWI was applied 24h post-exercise, we could observe  $T_{sk}$  reductions of  $13.90^{\circ}\text{C}$  ( $\pm 1.99$ ).

In relation of the muscular thickness, a time effect was observed ( $F_{(4, 160)} = 7.030$ ;  $p < 0.0001$ ;  $\mu_p^2 = 0.149$ ), an interaction of time x with or without the use of CWI ( $F_{(4, 160)} = 12.329$ ;  $p < 0.0001$ ;  $\mu_p^2 = 0.236$ ), an interaction of time x exercise or control arm ( $F_{(4, 160)} = 4.172$ ;  $p = 0.005$ ;  $\mu_p^2 = 0.094$ ), with or without the use of CWI effect ( $F_{(1, 40)} = 5.319$ ;  $p = 0.026$ ;  $\mu_p^2 = 0.117$ ) and an arm effect ( $F_{(1, 40)} = 5.996$ ;  $p = 0.019$ ;  $\mu_p^2 = 0.130$ ). No significant interaction was observed between time, with or without the use of CWI and the exercise or control arm.

As shown in the table 3, the muscular thicknesses in the exercise and control arms were significantly higher at 48h and 72 h post-exercise without the use of CWI ( $p = 0.029$ ,  $p = 0.028$  and  $p = 0.009$ ,  $p = 0.001$ , for the 48h, 72h, exercise and control arms, respectively). When the exercise and control arms were compared between with or without the use of CWI, in the moment post-exercise, the muscular thickness was significantly higher in the exercise arm in both situations ( $p=0.030$  and  $p=0.008$ , with and without use CWI, respectively).

When each arm with or without the use of CWI was analysed individually, a significantly higher muscular thickness was observed in the exercise arm with the use of CWI (Table 1): in the pre-exercise moment in relation to the 72h post-exercise moment ( $p=0.042$ ); and in the post exercise moment in the relation to the other moments ( $p=0.003$ ,  $p=0.003$ ,  $p=0.038$  and  $p<0.0001$ , pre-exercise and 24h, 48h, and 72h post-exercise, respectively). Also, in the exercise arm but without the use of CWI significantly fewer values of muscular thickness were observed in the moment pre-exercise in relation to the other moments ( $p<0.0001$ ,  $p=0.001$ ,  $p<0.0001$  and  $p=0.002$ , post- and 24h, 48h, and 72h post-exercise, respectively).

	Exercise Arm		Control Arm	
	CWI	WCWI	CWI	WCWI
<b>Pre Exercise</b>	26.72±4.93	26.21±4.25	24.98±5.04	25.42±4.87
<b>Post Exercise</b>	31.06±5.18§	33.51±4.59§	25.43±3.76‡	26.47±5.50‡
<b>24h PostE</b>	26.78±3.93 ††	30.50±5.57§	25.30±3.04	26.11±5.12
<b>48h PostE</b>	26.84±4.17††	31.90±4.08†§	23.66±3.72	28.04±4.90†§
<b>72h PostE</b>	23.83±4.98§††!	31.81±5.04†§	23.47±4.57	28.32±5.04†§#

**Table 3** – Mean ± standard deviations of muscular thickness (cm) in exercise and control arm with (CWI) or without (WCWI) use immersion bath.

† - p<0.05 between the use or not use immersion bath; ‡ - p<0.05 between control and exercise arm; § - p<0.05 in relation to the pre exercise moment; # - p=0.037 in relation to 24h post exercise moment; †† - p<0.05 in relation to the post exercise moment; ! - p=0.031 in relation to the 48h post exercise moment; PostE – Post Exercise

#### D. DISCUSSION

Cold Water Immersion has been applied as a muscular recovery therapy. However, there are multiple opinions about its efficacy when applied after an exercise protocol in the literature.

In order to understand the outcome and physiological events caused by CWI applications, we monitored  $T_{sk}$  during the entire process. When applying any method of cryotherapy, we believe that monitoring  $T_{sk}$  is of particular importance in order to understand the magnitude of physiological response as well as caution and safety of the subject submitted to low temperatures. Selfe et al. (2006) believe that in order to

achieve physiological responses from the application of cryotherapy, the methods have to be able to reduce the  $T_{sk}$  by at least 10-15°C.

In the present study, we observe  $T_{sk}$  reductions of 14.00°C ( $\pm 2.78$ ) when CWI was applied immediately post-exercise. Similarly, when cryotherapy was applied 24h post exercise, a  $T_{sk}$  reduction of 13.90°C ( $\pm 1.99$ ) was observed. However, even with these parameters documented, the physiological aspects from CWI application are not fully understood.

Delayed onset muscle soreness (DOMS) is a well-documented phenomenon, often occurring as the result of unaccustomed or high intensity exercise. Associated symptoms include muscle shortening, increased passive stiffness, swelling, decreases in strength and power, localised soreness, and disturbed proprioception. Depending on the specific nature of the exercise, the stress induced can be predominantly metabolic, mechanical or both [54]. In brief, RT inducing primarily metabolic stress in active skeletal muscles involves a high rate of aerobic and anaerobic energy transformation [232] and heat generation [233]. Both contribute to an increase in the generation of reactive oxygen species (ROS). ROS are highly reactive and can denature proteins, nucleic acids and lipids, which destabilise muscle cell structures including the sarcolemma and structures of the excitation–contraction-coupling system [234]. Damage to the excitation–contraction coupling system alters contraction kinetics, thereby reducing force-generating capacity and athletic performance, while disruption of the sarcolemma makes the muscle fibre more permeable [235].

The sustained high transformation of energy to support repeated contractions and increased intramuscular pressure imposed by hyperaemia [236] can also impose

mild hypoxic stress on the muscle fibres, promoting an accumulation of metabolites [232]. The accumulation of metabolites within the cell caused by a high metabolic rate increases the osmolality of the cell. Paired with increased permeability, the potential for cell swelling is enhanced [225].

Coupled with the damage by ROS and muscle fibre swelling, an exercise-induced inflammatory response is initiated. Although inflammation is required for the resolution of any muscle fibre damage resulting from the exercise insult, if excessive or unabated, the phagocytic activity of neutrophils and macrophages contribute to secondary muscle damage [237]. Secondary muscle damage, damage incurred by the inflammatory response to exercise and not the exercise bout per se, compounds the soreness and reduction in force-generating capacity experienced in the hours and days following a high-intensity exercise bout.

Loss of structural integrity of the sarcolemma and contractile system is directly induced by the strain experienced during contractions in response to mechanical stress. Sarcolemma disruption enhances cell permeability and swelling, while disruption to the excitation–contraction-coupling system impairs force-producing capability, and both contribute to soreness and reduced function [225].

In the present study, we tried to understand the behaviour of the acute and sub-acute swelling induced by an RT protocol, through evaluation of the MT variation during the post-exercise recovery period.

When both the exercise and control arms were compared with or without the application of the CWI protocol, in the post-exercise period, the MT was significantly higher in the exercise arm in both situations ( $p=0.030$  and  $p=0.008$ , with and without

CWI use, respectively), which was expected, and has been documented after RT training and an acute immunologic response to the aggression induced in the active musculature, which exponentially increases the muscular swelling [225, 235,237].

Also, the MT in both exercise and control arms were significantly higher 48h and 72h post-exercise when the subjects experimented a passive recovery compared with the CWI protocol application ( $p = 0.029$ ,  $p=0.028$  and  $p=0.009$ ,  $p=0.001$ , 48h, 72h and exercise, control arm, respectively).

When each arm was analysed individually, with or without CWI application, significantly higher muscular thickness was observed in the exercise arm with CWI application: in the pre-exercise period in relation to 72h post-exercise ( $p=0.042$ ); and in the post-exercise period in relation to the other moments ( $p=0.003$ ,  $p=0.003$ ,  $p=0.038$  and  $p<0.0001$ , pre-exercise and 24h, 48h, 72h post exercise, respectively). However, in the exercise arm, but without CWI application, significantly fewer values of muscular thickness were observed pre-exercise in relation to the other time-points ( $p<0.0001$ ,  $p=0.001$ ,  $p<0.0001$  and  $p=0.002$ , post and 24h, 48h, 72h post-exercise, respectively). These data showed that when CWI was applied immediately post-, as well as 24h post-hypertrophy RT protocol, the MT decreases significantly more in the recovery period (24h-72h post-exercise) when compared with passive recovery.

Despite the methodological differences, these data were according to the results obtained by Vaile et al. [238] who examined the effect of the 3 cryotherapy interventions (CWI, Hot Water Immersion and Contrast Water Therapy) in comparison to a passive rest recovery following a controlled RT protocol, ensuring that identical durations of recovery, water exposure and temperatures were maintained. Functional

and physical symptoms (Isometric squat (peak force); Squat jump (peak power); Blood markers (CK, LDH); Thigh circumference; Perceived soreness) of DOMS and the recovery of performance were assessed. Vaile et al. [238] showed that with CWI and contrast water therapy (but not hot water immersion), there was a significantly reduced degree of post-exercise swelling when compared to active recovery.

We tried to understand what is documented about the changes in swelling behaviour after a CWI protocol and what physiological events happen in order to achieve these results. Ihsan et al. [239] investigated the effect of CWI on NIRS-derived changes in localised muscle oxygenation and blood perfusion after high-intensity endurance exercise. It has to be noted that this study did not apply any RT protocol. Although the authors found that when the CWI protocol was applied after the subject performed 30 min of continuous running at 70% of their maximal treadmill velocity ( $V_{max}$ ), followed by 10 bouts of intermittent running at  $V_{max}$ : 1) muscle perfusion, as evidenced by the rise in post exercise tHb concentration, was attenuated with 15 min of CWI; and 2) tissue oxygenation index was increased during the 15 min of CWI, indicating reduced muscle metabolic activity.

The reduced blood flow to the injured area decreases the permeability of blood vessels, which may be a major factor in reducing the inflow of material to the injured muscle cell. In the present study, when each arm with or without the use of CWI was analysed individually, significantly higher muscular thickness was observed in the exercise arm with the use of CWI: in the pre-exercise period in relation to 72h post-exercise ( $p=0.042$ ); in the post-exercise moment in relation to the other moments ( $p=0.003$ ,  $p=0.003$ ,  $p=0.038$  and  $p<0.0001$ , pre-exercise and 24h, 48h, 72h post-

exercise, respectively). These results are in accordance with that stated by Ihsan et al. [239]; oedema induced by exercise appears to be biphasic, so that the initial increase in cell volume occurs acutely during the first two hours after exercise, due to the changes in osmotic pressure (accumulation of metabolites and extracellular proteins resulting from mechanical damage), while the subacute increase, between 24h and 96h after exercise, is due to secondary inflammatory damage.

The decrease in blood flow coupled with the decrease in cell metabolism may provide a lower consumption and oxygen to the cell, surviving for a longer period of ischaemia and reducing the metabolic stress experienced by the muscle cell after exercise, helping to reduce the disparity between the O<sub>2</sub> availability and consumption. The function of the mitochondrial respiratory chain significantly contributes to ROS production by muscle cells. Thus, reducing the rate of mitochondrial energy production by the decreased temperature can be expected to result in more limited damage by ROS [223,239,240]. Additionally, compressive forces commonly combined with cold (i.e. hydrostatic forces of water) structurally limit swelling and fluid accumulation, while facilitating the removal of wastes and increasing central blood volume [82].

Recently, Roberts et al [223] added some new data that were in accordance with this theory. The authors examined the effects of CWI and active recovery on cardiac dynamics, muscle haemodynamics, tissue temperature and strength following resistance exercise. On separate days, 10 men performed resistance exercise, followed by 10 min CWI at 10°C or 10 min of low-intensity cycling. CWI reduced haemodynamics and tissue temperature, and helped to maintain muscle strength after resistance exercise.

It seems evident that CWI can reduce muscle swelling in the post-exercise recovery days. However, if the swelling muscle is the main cause of loss of performance, loss of function, reduced capacity to generate power and induces muscular pain, it is expected that the reduction of muscular swelling will attenuate these side effects. In this study, the effects of CWI on muscle function, pain or capacity to generate strength were not directly investigated, but a few studies have recently been documented with that aim which give support to our investigation. Vaile et al [238] stated that when a specific movement (squat jump) was performed requiring dynamic power, CWI enhanced the recovery of both isometric force production and squat jump performance, compared with an active recovery.

Also, [223] showed another new and important finding in their study; cold-water immersion prevented a decrease in maximal isometric strength after resistance exercise. In contrast, strength remained below pre-exercise values for at least 40 min after active recovery. To supplement these data Roberts et al. [222] tried to understand how CWI influences the recovery of maximal and submaximal muscle function following high-intensity resistance exercise in another investigation. The authors suggest that cold-water immersion after resistance exercises allows athletes to complete more work during subsequent training sessions. Compared with active recovery, cold-water immersion did not alter the recovery of maximal strength or countermovement jump performance. However, it did enhance the recovery of submaximal muscle function during a high-intensity resistance exercise test.

These findings add to existing knowledge of the performance benefits and physiological effects of cold-water immersion after exercise; there is evidence that

CWI after an RT protocol can reduce muscle swelling, enhance submaximal muscle function and prevent any decrease in maximal isometric strength.

These are important findings regarding CWI effects, especially for athletes, as recovery between training sessions is a highly relevant factor in a long-term adaptation to unaccustomed exercise and in the performance of the following sessions. The recovery time is particularly important for athletes who are often subjected to daily and weekly training sessions, which have yet to be combined with competitions.

Muscle inflammation as well as the metabolic product and the muscle swelling play an important role for the resolution of any muscle fibre damage resulting from the exercise insult and for those who perspective muscle hypertrophy. Thus, a paradox between the use of CWI for acute reduction in muscle swelling to facilitate recovery and the potential negative effects caused by blunting the stress response may exist.

Roberts et al [88] compared the effects of CWI and active recovery on changes in muscle mass and strength after 12 weeks of strength training. The authors also examined the effects of these two treatments on hypertrophy signalling pathways and satellite cell activity in skeletal muscle. CWI attenuated long-term gains in muscle mass and strength. It also delayed and/or suppressed the activity of satellite cells and kinases in the mTOR pathway during recovery from strength exercise.

In summary, the evaluation of MT by Ultrasound gives evidence that CWI after an RT protocol, as well as 24h post-exercise, may reduce muscle swelling in the post-exercise days when compared with passive recovery. We did not directly evaluate muscle function and hypertrophy gains. Although, in relation to the recently documented studies, data gives strong evidence that CWI and the reduction in muscle

swelling can prevent reductions in muscle function and strength production after an RT. On the other hand, a reduction in muscle swelling as a result of a CWI protocol may attenuate long-term gains in muscle mass and strength.

#### **E. PRATICAL APPLICATIONS**

Individuals and athletes who use resistance training to improve athletic performance, recover from injury or maintain their health, should therefore reconsider using CWI as an adjuvant to their training, although, in order to recover muscle function and performance, CWI seems to be a useful method.

#### **Acknowledgements**

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## **Appendix C – A novel method to reduce the impact of countermovement jump monitoring in professional rugby athletes**

**Tavares F**, McMaster T, Healey P, Smith TB, Driller M. A novel method to reduce the impact of countermovement jump monitoring in professional rugby athletes.

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Jumps are frequently used in applied settings to monitor neuromuscular performance, and adaptations to training. The ground reaction forces associated with the landing phase of a countermovement jump may increase the risk of injury, in particular in strength and power athletes with high body masses, including rugby athletes. When jumping to a box, landing forces will decrease substantially, therefore this option may be implemented during training routines to reduce the risk of injury.

Understanding the reliability of different force-related measures is essential in order to accurately monitor jump performance. Thus, **Study Three** aimed to measure the validity of different force-related measures obtained during a countermovement jump onto a box in comparison to a *traditional* countermovement jump; and to measure the reliability of different force-related measures of the two jumping conditions. Given that the same protocols were utilised in subsequent studies, establishing the reliability of the setup and the measures was important.

## **Abstract**

The countermovement jump (CMJ) is widely used to monitor jump performance, with greater interest being demonstrated in the propulsive phase. When landing from a CMJ, high forces are produced, which can increase the risk of injury. The present study aimed to test the validity and reliability of a countermovement jump to a box (CMBJ) where the forces associated with the landing are reduced. Eighteen professional rugby athletes (age =  $22 \pm 2$  years; body mass =  $104.2 \pm 13.0$  kg; height =  $187.4 \pm 7.1$  cm) performed 3 CMJ and 3 CMBJ on 3 different occasions. Net impulse (N.s), peak and mean absolute and relative force (N; N/kg) were obtained from a force plate system. The kinetic validity of the CMBJ was assessed by calculating the intra-class correlation coefficient, Pearson product-moment correlation, Cohen's effect sizes and statistical hypothesis testing (paired T-test) in comparison to the CMJ. Intra-day and inter-day reliability was assessed for each variable for both jumping conditions by calculating typical error, within subject coefficient of variation and intra-class correlation coefficient. Non-significant, *trivial* differences between the CMJ and CMBJ were observed for all jump variables. Low within-subject variability was observed between the CMJ and CMBJ for all variables. Inter-day and intra-day variability showed good reliability and an *almost perfect* inter-day agreement score. In conclusion, net impulse, peak and mean force and relative peak and mean force obtained from a CMBJ are valid and reliable to monitor jump performance. This data demonstrates that the CMBJ is a viable alternative to monitor jump performance in athletes.

**Keywords:** Box jump, kinetic, neuromuscular, monitor

## **Introduction**

The validity and reliability of different jumping tests as well as equipment and protocols used to measure jump performance have been widely explored in the scientific literature [113]. In particular, the countermovement jump (CMJ) is frequently utilised to monitor and assess acute and chronic neuromuscular adaptations and fatigue in athletes [241]. Producing and absorbing ground reaction force are two vital components to effectively execute a CMJ. The propulsion (concentric) phase of the CMJ is governed by net impulse, which inevitably determines take-off velocity and subsequent jump height [242]. Moreover, ground reaction force characteristics of the eccentric and amortization phases were recently shown to be strongly correlated with jump performance [243]. The magnitude of ground reaction force and impulse produced during the propulsive phase provides insight into the mechanical properties of the neuromuscular system [244,245].

The landing phase of the CMJ is also important to consider from an impact and injury prevention perspective, as high ground reaction forces are associated with landing from a CMJ [246,247] and also to a higher incidence of injuries [248]. The magnitude of ground force experienced during landing from a jump varies greatly between individuals (2 to 17 x body weight) and is influenced by the individual's jump height and ability to attenuate landing forces [247]. Large ground reaction forces acting on the body during the landing phase have been associated with an increased risk of lower limb injury [248,249]. Moreover, the risk of lower limb injury may be increased when a traditional CMJ is used as a fatigue-monitoring test, as it is performed when athletes are in a fatigued state [5]. In addition, the high body mass of some athletes (e.g. rugby,

American football.) can result in an increased landing ground reaction force and possibly increase the risk of lower limb injuries.

Previous research has identified that increasing flexion at the hips, knees and ankles during the time of ground contact can reduce the magnitude of landing ground reaction force due to an increased absorption time to dissipate force [246,247,249]. The literature indicates that reductions in the magnitude of impact force (0.4 to 1.0 x bodyweight) may occur with improved landing technique through various feedback mechanisms [249–254]. Moreover, the magnitude of ground reaction forces experienced during landing could be further reduced by utilizing a countermovement box jump (CMBJ). During a CMBJ, the athlete lands at a height above the take-off point and based on the laws of physics, ground reaction forces are theoretically reduced. In support of this theory, studies have found that peak ground reaction forces were reduced by 15 to 20% for every 0.20 m reduction in drop height [253,254]. However, no research to date has investigated the use of the CMBJ as a monitoring tool in elite athletes.

Therefore, the purpose of this investigation was to examine the kinetic validity and reliability of the CMBJ. We hypothesise that CMBJ is valid and reliable in comparison to a traditional CMJ and therefore could be used as a safer alternative of monitoring jump performance in elite athletes.

## Methods

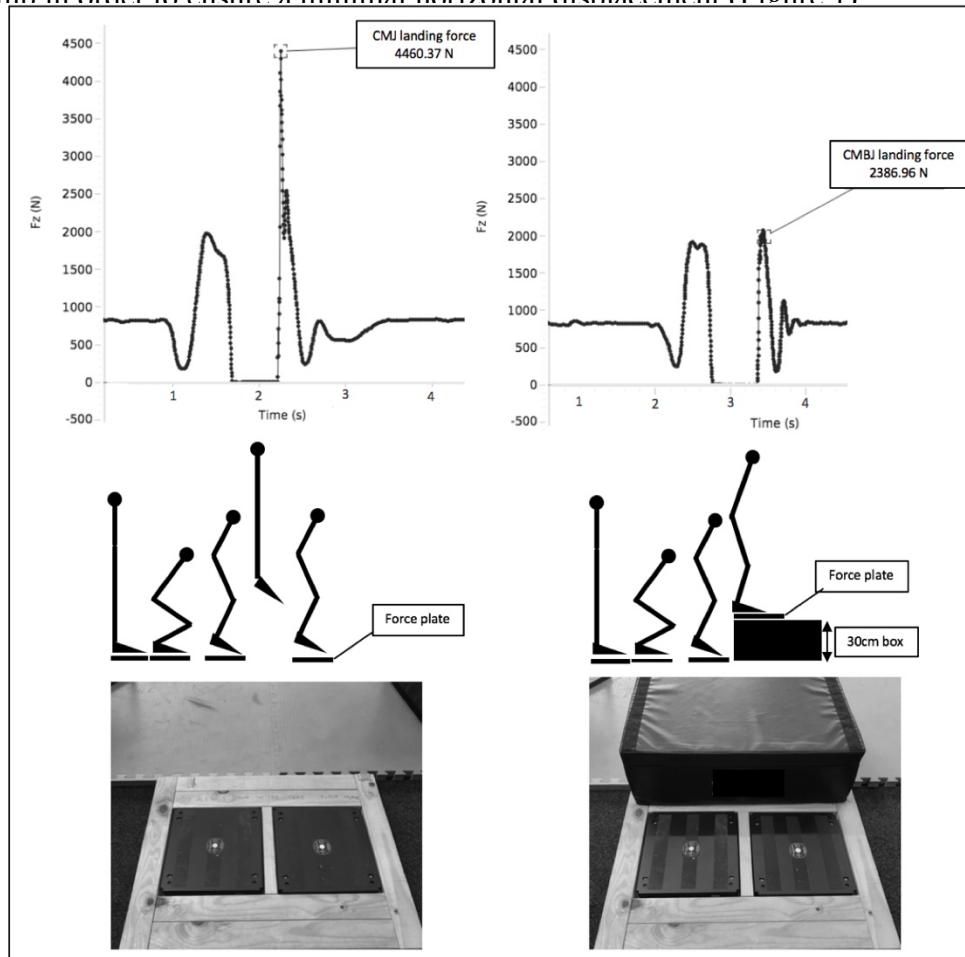
### *Participants*

Eighteen male professional rugby athletes (age =  $22 \pm 2$  y body mass =  $104.2 \pm 13.0$  kg; height =  $187.4 \pm 7.1$  cm) volunteered to participate in the current study. The sample size in the current study is similar to previous research investigating the validity and reliability of jumping performance using professional athletes (e.g. 15 elite Australian-rules football [113]). Athletes were members of a team competing in the super rugby competition, the major competition in the southern hemisphere. Data were obtained during a 15-day period during pre-season, on the morning of the first training day of 3 weeks. The reason to collect the data on the day one of each week was because the athletes had ~65 hours of rest from the previously training session (e.g. last training session of previous week). Athletes were familiar with both the CMJ and CMBJ as both exercises were part of their regular training routines. Despite of the landing environment, athletes were instructed to jump as high and quick as possible. Exclusion criteria of this study included the presence of any musculoskeletal injuries that may have prevented athletes from participating to their full abilities. Written informed consent was obtained from each participant, and ethical approval was obtained from the Human Research Ethics Committee of University of Waikato.

### *Data Collection Procedures*

In order to compare the reliability and the differences between two different jumping conditions, athletes were asked to perform a CMJ and a CMJ to a 30-cm high box (CMBJ) on three separate occasions (Figure 1). The dual force plates (37 x 37 cm;

PASCO PS 2142, Roseville, CA, USA) were embedded in a purpose-built platform to facilitate safe landing for the athletes. The 30 cm box was positioned adjacent to the setup in order to ensure a minimal horizontal displacement (Figure 1)



**Figure 1.** An example of the ground reaction forces of a countermovement jump (top and bottom left) and countermovement box jump (top and bottom right) obtained from an 85 kg athlete. The force plate was placed on top of the 30 cm box for this schematic example only.

Prior to commencing the study, the jumping order was randomized and this order was maintained for the 3 testing sessions for each athlete. Each testing session was performed after a minimum of 48 hours following the last training session and occurred between 8:00 a.m. and 8:30 a.m. each morning. Following a standardized warm-up

comprised of dynamic stretches and movements (e.g. one-leg standing knee flexion, bodyweight squats, bodyweight CMJs) athletes performed three CMJ or three CMBJ with ~15 seconds of interval between each jump. Two minutes rest was given between the first jumping condition and the second jumping condition. Each trial started with the participants standing on the top of the force plates with their knees fully extended and the hands on hips to eliminate the influence of arm swing [113]. Participants were then instructed to descend to a self-selected countermovement depth and to jump as high and as quick as possible [123].

#### *Data Analysis Procedures*

The dual force plates were used to measure force at a sampling rate of 500 Hz. The total ground reaction force was calculated as the sum along the vertical axis of the left and right force plate measures. The force plates were connected to an analog-to-digital converter (SPARKlink), which was then connected to a computer running the Pasco Capstone v1.4.0 software (PASCO, Roseville, California, USA) through a USB port. Each trial was then analyzed using a custom-designed Labview (National Instruments, TX, USA) force plate analysis software and the variables of interest were calculated [255]. Before each jump, the force platforms were reset to ensure the measured force was zeroed. Initiation of the eccentric phase of the CMJ was defined to occur when ground reaction force dropped below 2.5% of bodyweight [256]. The end of the propulsive phase of the jump was calculated from when the force dropped to zero, the difference between the initiation threshold and zero force is termed the time to takeoff (start of the flight phase) [256,257]. Vertical ground reaction force was divided by the mass of the participant at each time point to determine the acceleration of the center of

mass [256]. Acceleration due to gravity was subtracted from the calculated acceleration data to ensure that only the acceleration produced by the participant was obtained [256]. The integrated area under the force-time curve represents total impulse; to calculate net impulse, body weight was subtracted from total impulse [258]. Body mass normalizations for mean force and peak force were calculated according to the participant's mass obtained at the time of each session.

### *Statistical Analysis*

The validity of the different CMBJ kinetic variables were calculated by comparing each selected variable to the criterion measure, the CMJ. The highest score of the selected variables for each session was obtained and used for validity analysis. The kinetic validity of the CMBJ was assessed by calculating the intraclass correlation coefficient (ICC), Pearson product-moment correlation ( $r$ ), Cohen's effect sizes ( $d$ ) and statistical hypothesis testing in comparison to the CMJ. The data collected was analysed using a Statistical Package for Social Sciences (Version 22.0, SPSS Inc., IBM, Chicago). The Shapiro-Wilk test was performed to assess normality for each variable and a paired T-test with the significance level set as  $p < 0.05$  was used to analyze statistical differences between jump conditions. Magnitudes of the standardised effects between the CMJ and CMBJ were assessed by the validity correlations developed by Hopkins [259] and interpreted using thresholds of  $< 0.2$ ,  $0.2$ ,  $0.6$  and  $1.2$  for *trivial*, *small*, *moderate* and *large*, respectively [139]. Where the 90% confidence limits overlapped *small* positive and negative values, the effect was deemed *unclear*. Pearson product-moment correlations were interpreted as follows: *very high* ( $r = 0.90 - 1.00$ ), *high* ( $r = 0.70 - 0.90$ ), *moderate* ( $r = 0.50 - 0.70$ ), and *negligible* ( $r = 0.00 - 0.30$ ) [260]. Based on

previous research, a coefficient of variation (CV) of  $\leq 8\%$  was used to establish the validity for the variables of interest [261,262].

Intra-day and inter-day reliability was assessed for each variable of interest for both jumping conditions by calculating typical error (TE), within subject coefficient of variation (CV%) and ICC [259]. The TE upper and lower 90% confidence intervals were also determined [259]. For the intra-day analysis, the data was calculated for each day (i.e. reliability of intra-day 1, reliability of intra-day 2 and reliability of intra-day 3) and the average of the three days was reported and used for analysis. For the inter-day analysis, the highest score of each day for each variable of interest was used. ICC thresholds were interpreted as follows: *poor* (0–0.2), *fair* (0.3–0.4), *moderate* (0.5–0.6), *strong* (0.7–0.8), and *almost perfect* ( $> 0.8$ ) [263]. An ICC  $> 0.70$  was used to establish a variable as reliable, as used previously [113,115].

## Results

### *Validity*

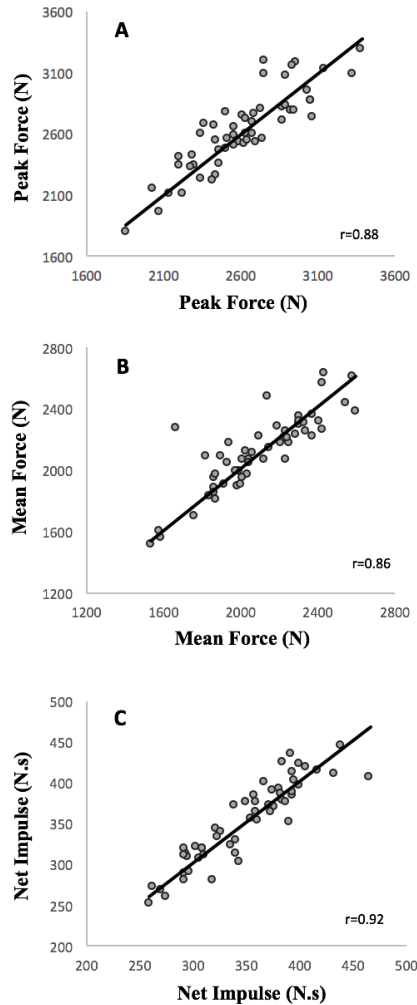
The validity measures of the CMBJ are displayed in Table 1. The Pearson product-moment correlation between the CMJ and CMBJ for impulse and absolute peak and mean force are presented in Figure 2. No significant differences ( $p > 0.05$ ) were observed for any measure between the CMJ and the CMBJ. Additionally, the effect sizes of all measures were found to be *trivial* between jumps. For all of the studied measures, the CV% ranged between 5.6 – 6.6%, therefore were considered acceptable ( $CV \leq 8\%$  [261,262]). Pearson product-moment correlations between the CMJ and CMBJ were considered *high* for both relative and absolute peak force ( $r = 0.86$  and

0.88, respectively) and also for relative and absolute mean force ( $r = 0.81$  and  $0.86$ , respectively), and *very high* for net impulse ( $r = 0.92$ ) (Table 1).

**Table 1.** Kinetic validity between the countermovement jump (CMJ) and countermovement box jump (CMBJ).

	Mean (± SD)		CV% (90% CI)	<i>r</i>	P-value	<i>d</i>
	CMBJ	CMJ				
Peak Force (N)	2617.3 (± 328.9)	2620.3 (± 329.1)	6.1 (5.4 – 7.4)	0.88 (0.82 – 0.92)	0.893	0.00 ( <i>trivial</i> )
Mean Concentric Force (N)	2110.8 (± 247.9)	2097.9 (± 259.5)	6.6 (5.7 – 8.0)	0.86 (0.78 – 0.91)	0.487	-0.03 ( <i>trivial</i> )
Relative Peak Force (N/kg)	25.0 (± 3.1)	25.0 (± 3.1)	6.2 (5.3 – 7.5)	0.86 (0.79 – 0.91)	0.986	-0.05 ( <i>trivial</i> )
Relative Mean Force (N/kg)	20.1 (± 2.1)	20.0 (± 2.3)	6.5 (5.6 – 7.8)	0.81 (0.71 – 0.88)	0.365	0.01 ( <i>trivial</i> )
Net Impulse (N·s)	351.4 (± 50.5)	350.0 (± 49.1)	5.6 (4.8 – 6.8)	0.92 (0.88 – 0.95)	0.618	-0.07 ( <i>trivial</i> )

*Note.* Data presented includes the coefficient of variation percentage (CV%), Pearsons *r*, p-values and Cohen's *d* for comparison between jumps.



**Figure 2.** Pearson product-moment correlation ( $r$ ) of A: Peak force (N); B: Mean force (N); and C: Net impulse (N.s) between the CMJ and CMBJ conditions.

#### *Intra-day reliability*

The intra-day reliability measures for both jumping conditions are displayed in Table 2. All measures for both jumping conditions showed a good reliability with CV% ranging between 3.7 and 4.4% [261,262]. An *almost perfect* intra-day agreement was observed for the ICC scores for all measures of both the CMJ and CMBJ (ICC = 0.85 – 0.95) trials (Table 2).

**Table 2.** Intra-day reliability of the kinetic variables for the countermovement jump (CMJ) and countermovement box (CMBJ) jump.

	Mean (± SD)		TE (90% CI)		CV% (90% CI)		ICC (90% CI)	
	CMBJ	CMJ	CMBJ	CMJ	CMBJ	CMJ	CMBJ	CMJ
Peak Force (N)	2510.8 (± 299.1)	2527.0 (± 320.9)	115.2 (95.3 – 151.9)	100.9 (83.3 – 132.4)	4.4 (3.6 – 5.9)	4.0 (3.6 – 4.9)	0.86 (0.74 – 0.93)	0.91 (0.83 – 0.96)
Mean Concentric Force (N)	2039.3 (± 243.7)	2038.8 (± 263.0)	85.9 (71.0 – 113.3)	69.9 (57.7 – 91.8)	4.2 (3.4 – 5.7)	3.7 (3.1 – 4.9)	0.88 (0.78 – 0.94)	0.94 (0.88 – 0.97)
Relative Peak Force (N/kg)	24.0 (± 2.8)	24.1 (± 3.0)	1.1 (0.9 – 1.4)	1.0 (0.8 – 1.3)	4.4 (3.6 – 5.9)	4.0 (3.6 – 4.9)	0.86 (0.74 – 0.93)	0.90 (0.82 – 0.95)
Relative Mean Force (N/kg)	19.4 (± 2.0)	19.4 (± 2.2)	0.8 (0.7 – 1.1)	0.7 (0.6 – 0.9)	4.2 (3.4 – 5.7)	3.7 (3.0 – 4.9)	0.85 (0.72 – 0.93)	0.92 (0.84 – 0.96)
Net Impulse (N·s)	339.5 (± 49.2)	338.5 (± 47.1)	14.3 (11.8 – 18.8)	11.5 (9.5 – 15.2)	4.4 (3.6 – 6.0)	3.4 (2.8 – 4.5)	0.92 (0.85 – 0.96)	0.95 (0.90 – 0.98)

*Note.* Data presented includes the mean and standard deviation (SD), typical error of measurement (TE) expressed in raw values and as a coefficient of variation (CV%) and intra-class correlation (ICC) for each variable. 90 % confidence intervals (CI) presented for TE, CV% and ICC.

### *Inter-day reliability*

The inter-day reliability measures for both jumping conditions are displayed in Table 3. All measures for both conditions showed good reliability, with CV's between 3.91 and 6.13% being below the defined threshold (< 8% [261,262]). An *almost perfect* inter-day agreement was observed for the ICC scores for all measures (ICC = 0.88 – 0.89) of the CMJ (Table 3). For the CMBJ an *almost perfect* inter-day agreement was observed for absolute (ICC = 0.90) and relative (ICC = 0.88) mean force, absolute peak force (ICC = 0.80) and net impulse (ICC = 0.87), with a *strong* inter-day agreement was observed for relative peak force (ICC = 0.77).

**Table 3.** Inter-day reliability of the kinetic variables for the countermovement jump (CMJ) and countermovement box jump (CMBJ).

	Mean (± SD)		TE (90% CI)		CV% (90% CI)		ICC (90% CI)	
	CMBJ	CMJ	CMBJ	CMJ	CMBJ	CMJ	CMBJ	CMJ
Peak Force (N)	2617.3 (± 328.9)	2620.3 (± 329.1)	156.2 (129.0 – 205.1)	117.6 (97.1 – 154.4)	6.1 (5.0 – 8.1)	4.6 (3.8 – 6.0)	0.80 (0.63 – 0.90)	0.89 (0.78 – 0.95)
Mean Concentric Force (N)	2110.8 (± 247.9)	2097.9 (± 259.5)	82.9 (68.5 – 108.9)	86.8 (71.7 – 114.0)	3.9 (3.2 – 5.2)	4.2 (3.5 – 5.6)	0.90 (0.81 – 0.95)	0.90 (0.81 – 0.95)
Relative Peak Force (N/kg)	25.0 (± 3.1)	25.0 (± 3.1)	1.5 (1.3 – 2.0)	1.2 (1.0 – 1.5)	6.0 (4.9 – 8.0)	4.6 (3.8 – 6.1)	0.77 (0.59 – 0.88)	0.88 (0.77 – 0.94)
Relative Mean Force (N/kg)	20.1 (± 2.1)	20.0 (± 2.3)	0.8 (0.6 – 1.0)	0.9 (0.7 – 1.1)	3.6 (3.0 – 4.8)	4.3 (3.5 – 5.7)	0.88 (0.78 – 0.94)	0.88 (0.77 – 0.94)
Net Impulse (N·s)	351.4 (± 50.5)	350.0 (± 49.1)	19.1 (15.8 – 25.1)	18.2 (15.0 – 23.9)	5.7 (4.7 – 7.5)	5.1 (4.2 – 6.8)	0.87 (0.76 – 0.94)	0.88 (0.77 – 0.94)

*Note.* Data presented includes the mean and standard deviation (SD), typical error of measurement (TE) expressed in raw values and as a coefficient of variation (CV%) and intra-class correlation (ICC) for each variable. 90% confidence intervals (CI) presented for TE, CV% and ICC.

## Discussion and Implications

The purpose of the current investigation was to examine the kinetic validity and reliability of a counter-movement jump to a 30 cm box. We hypothesized that CMBJ is valid and reliable in comparison to a traditional CMJ and therefore could be used as a safer alternative of monitoring jump performance in elite athletes. The primary findings of the present study were that the CMBJ is a valid alternative to monitor jump performance in athletes as evidenced through non-significant differences and *trivial* effects for all measures in comparison to a CMJ [261,262]. In addition, net impulse (N·s) obtained from CMBJ was demonstrated to be *very highly* correlated ( $r = 0.92$ ) to the CMJ. The remaining kinetic variables (i.e. mean and peak concentric force) were also *highly* correlated ( $r = 0.70 - 0.90$ ) with the CMJ. To the authors' knowledge, no previous studies have compared the CMBJ to a CMJ. Furthermore, no previous studies have measured any kinetic parameters during a CMBJ.

The intra-day reliability was assessed between three jumps within each condition. Although the highest score is normally selected to analyse the inter-day reliability and regularly used to track changes (e.g. monitor neuromuscular fatigue) within athletic populations, it is important to understand the stability of a measure over the course of various trials. For this reason, intra-day reliability is typically presented in studies investigating new methods of monitoring jumping performance [262,264]. According to established reliability thresholds ( $CV < 8\%$  and  $ICC > 0.70$ ), all of the measured variables from the CMJ and CMBJ were considered reliable. In addition, our results are in accordance with previous research that have investigated the intra-day reliability for the variables of interest in the CMJ ( $CV = 2.2-3.9$ ;  $ICC = 0.92-0.93$ ) [264,265].

Gathercole et al.[264] observed low intra-day variability for total impulse (CV = 2.2%), relative net impulse (CV = 3.1), mean force (CV = 2.2%) and peak force (CV = 2.8%) across four CMJ performed by male college-level team-sport athletes. The fact that the participants performed six CMJ and the four most consistent CMJ were selected, may justify the slightly lower CV's observed in their study [264]. Hori et al.[265] also reported similar intra-day reliability for peak force (ICC = 0.92; CV = 4.1%) and mean force (ICC = 0.93; CV = 3.9%) across two CMJ trials performed by 24 male active university students.

The inter-day measures were also deemed reliable during the CMJ and CMBJ according to the same established reliability thresholds. In general, with the exception of relative peak force obtained during the CMBJ, our results for all other kinetic variables are within the range observed for different jumping conditions (ICC = 0.83 – 0.99; CV < 6.5% [241]). Similar findings were observed in previous research investigating the inter-day reliability of net impulse, peak and mean force obtained from a CMJ in athletic populations. For example, in volleyball (ICC = 0.96; CV = 3.5% [266]), rugby (CV = 1-4.3%; ICC = 0.88 – 0.94 [113, 264,267]) and track and field (ICC = 0.97; CV = 6.4% [268]) athletes, the same kinetic variables were demonstrated to be reliable between sessions. Although, within the defined thresholds for accepting the reliability of a measure, relative peak force (N/kg) obtained from the CMBJ was found to have lower inter-day-agreement (ICC = 0.77) in comparison to the other CMBJ and CMJ kinetic variables (ICC = 0.80 – 0.90). The lower ICC score observed for the relative peak force during the CMBJ, suggests that the usage of peak and mean absolute force, relative mean force or net impulse for the CMBJ may be more

appropriate.

The CMJ is one of the most commonly used tests to monitor jumping performance in athletic population [241]. Although kinetic and kinematic parameters can be obtained from the eccentric and amortization phase [243], greater interest has been shown in the propulsive phase [73,264]. Moreover, in the applied setting, the measurement of landing forces is not regularly investigated. As aforementioned, forces associated to landing from a CMJ can be up to 17 times the subject body weight [247], therefore increasing the risk of injury. In highly-trained athletes, like the ones that participated in the current study, with body masses ranging from ~85 to 123 kg and well developed jumping abilities, landing forces can be a concern even when correct landing technique is expected. Although in a non-fatigue state (as is the case in the current study) it is not likely that athletes would suffer an injury landing from CMJ; however, when this test is used in a daily base and performed under fatigue, the risk of injury is increased [264]. We had hypothesised that CMBJ would be valid and reliable in comparison to a traditional CMJ to monitor jump performance in elite athletes. According to our hypothesis, given both the validity and reliability scores observed for the CMBJ, the absolute and peak force, the relative and mean force and the net impulse can be utilized to monitor jumping performance in athletes. Although landing forces during the CMBJ were only measured to provide a schematic representation of the impact forces on landing (Figure 1), there is a strong rationale based on the laws of physics to expect a reduction in landing forces when an athlete lands at a height above the take-off point. Future research should quantify the resultant ground reaction forces of landing at different box heights to gain a better understanding of CMBJ landing kinetics. In

addition, the reliability of athletes from varying competitive levels, different sports and female athletes should also be investigated. In order to understand the sensitivity of the CMBJ to monitor fatigue, future research should also investigate the timeframe for different measures to return to baseline after a fatigue-inducing test [111].

## **Conclusion**

The findings from the present study demonstrate that the CMBJ is a valid and reliable test to assess and monitor jump performance in professional rugby athletes. Therefore, the CMBJ offers an alternative to the CMJ for monitoring athletes, while providing lower impact forces, and possibly reducing the risk of injury. Our findings are particularly important for strength and conditioning coaches and researchers who regularly monitor athletes during periods where fatigue levels are increased (e.g. testing neuromuscular performance during the training week), as athletes may be more susceptible to injury.

# Appendix D – Ethical approval

The University of Waikato  
Private Bag 3105  
Gate 1, Knighton Road  
Hamilton, New Zealand

Human Research Ethics Committee  
Telephone: +64 7 838 5173  
Email: aand@waikato.ac.nz



15 December 2016

Francisco Tavares  
C/- Matt Driller  
Te Oranga, School of Human Development and Movement Studies,  
The University of Waikato,

Dear Francisco

**HREC(Health) #12 : Effect of cold water immersion on the readiness and adaption in elite rugby athletes**

Members of the University of Waikato Human Research Ethics Committee (Health) considered the amended ethics application you forwarded with your email dated 14 December 2016.

As advised in our email of 15 December 2016, the ethics application has now been approved.

Regards,



---

**Prof Mark Apperley**  
**Acting Chairperson**  
**University of Waikato Human Research Ethics Committee (Health)**

*Te Kura Toi Tangata*  
**Faculty of Education**  
The University of Waikato  
Private Bag 3105  
Hamilton, New Zealand, 3240

FEDU Ethics Committee  
fedu\_ethics@waikato.ac.nz  
07 8384500 ext. 7870  
www.waikato.ac.nz/education



THE UNIVERSITY OF  
**WAIKATO**  
*Te Whare Wānanga o Waikato*

9 October 2018

Dear Francisco

**FEDU Ethics Application Approved-FEDU062/16**

I am pleased to advise you that your ethics application for the project entitled "Usage and perceptual understanding of recovery modalities between elite and amateur rugby athletes" was approved by Te Kura Toi Tangata Faculty of Education Ethics Committee on 7 July 2016.

Please be aware that the Te Kura Toi Tangata FEDU Ethics Committee must be advised (by memo) of any changes to the details recorded in your ethics application. Please send any such advice to fedu.ethics@waikato.ac.nz. You will receive a memo of approval once the change(s) has been considered.

We wish you all the best with your research.

Kind regards

A handwritten signature in purple ink, appearing to read 'Jayne Clark'.

Chair

Te Kura Toi Tangata Faculty of Education Ethics Committee

# Appendix E – Co-authorship forms



## Co-Authorship Form

Postgraduate Studies Office  
 Student and Academic Services Division  
 Wahanga Ratonga Matauranga Akonga  
 The University of Waikato  
 Private Bag 3105  
 Hamilton 3240, New Zealand  
 Phone +64 7 838 4439  
 Website: <http://www.waikato.ac.nz/sas/postgraduate/>

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Please indicate the chapter/section/pages of this thesis that are extracted from a co-authored work and give the title and publication details or details of submission of the co-authored work.

Chapter 2 – Fatigue and recovery in rugby: A review

Tavares, F., Smith, T. B., Driller, M. (2017). Fatigue and recovery in rugby: A review. *Sports Medicine*, 47(8), 1515-1530.

Nature of contribution by PhD candidate	Analysis of literature, manuscript preparation and journal submission.
Extent of contribution by PhD candidate (%)	90

### CO-AUTHORS

Name	Nature of Contribution
Matthew Driller	Supervision of all stages and critical revision of the manuscript
Brett Smith	Support of all stages and critical revision of the manuscript

### Certification by Co-Authors

The undersigned hereby certify that:

- ❖ the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and

Name	Signature	Date
Matthew Driller		03/10/2018
Brett Smith	 <small>Digitally signed by Brett Smith DN: cn=Brett Smith, o=University of Waikato, ou=Sport and Leisure Studies Dept. email=brett.smith@waikato.ac.nz, c=NZ Date: 2018.10.10 13:36:35 +1300</small>	03/10/2018

July 2015



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Postgraduate Studies Office  
 Student and Academic Services Division  
 Wahanga Raranga Matauranga Akonga  
 The University of Waikato  
 Private Bag 3105  
 Hamilton 3240, New Zealand  
 Phone +64 7 838 4439  
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Chapter 3 - The usage and perceived effectiveness of different recovery modalities in amateur and elite rugby athletes.

Tavares, F., Healey, P., Smith, T. B., Driller, M. (2017). The usage and perceived effectiveness of different recovery modalities in amateur and elite rugby athletes. *Performance Enhancement & Health*, 5(4), 142-146.

Nature of contribution by PhD candidate	Development of study design, data collection and analysis, manuscript preparation and journal submission.
Extent of contribution by PhD candidate (%)	90

### CO-AUTHORS

Name	Nature of Contribution
Matthew Driller	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript
Brett Smith	Support of all stages (study design, data collection and analysis) and critical revision of the manuscript
Phil Healey	Support with data collection and development of study design

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Matthew Driller		03/10/2018
Brett Smith	 <small>Digitally signed by Brett Smith DN: cn=Brett Smith, o=University of Waikato, ou=Sport and Exercise Studies Dept, email=brett@waikato.ac.nz, c=NZ Date: 2018.10.03 10:42:39 +1200</small>	03/10/2018
Phil Healey		03/10/2018

July 2015



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Postgraduate Studies Office  
 Student and Academic Services Division  
 Wahanga Ratoranga Matauranga Akonga  
 The University of Waikato  
 Private Bag 3105  
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Chapter 4 - A novel method to reduce the impact of countermovement jump monitoring in professional rugby athletes.

Tavares, F., McMaster, T., Healey, P., Smith, T. B., Driller, M. (2018). A novel method to reduce the impact of countermovement jump monitoring in professional rugby athletes. *Journal of Athletic Enhancement*, 7(1)

Nature of contribution by PhD candidate

Development of study design, data collection and analysis, manuscript preparation and journal submission.

Extent of contribution by PhD candidate (%)

85

### CO-AUTHORS

Name	Nature of Contribution
Matthew Driller	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript
Brett Smith	Support of all stages (study design, data collection and analysis) and critical revision of the manuscript
Phil Healey	Support with data collection and development of study design
Travis McMaster	Support with data collection and analysis and critical revision of the manuscript

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July 2015



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 Student and Academic Services Division  
 Wahanga Ratonga Matauranga Akonga  
 The University of Waikato  
 Private Bag 3105  
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Chapter 5 (Study A) - Short-term effect of training and competition on muscle soreness and neuromuscular performance in elite rugby athletes.	
Tavares F., Healey P., Smith TB., Driller, M. (2018). Short-term effect of training and competition on muscle soreness and neuromuscular performance in elite rugby athletes. <i>Journal of Australian Strength and Conditioning</i> , 26(1), 11-17.	
Nature of contribution by PhD candidate	Development of study design, data collection and analysis, manuscript preparation and journal submission.
Extent of contribution by PhD candidate (%)	90

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Matthew Driller	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript
Brett Smith	Support of all stages (study design, data collection and analysis) and critical revision of the manuscript
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Brett Smith	 <small>Digitally signed by Brett Smith DN: cn=Brett Smith, o=University of Waikato, ou=Sport and Leisure Studies Dept, email=b.smith@waikato.ac.nz, date=2018.10.10 16:43:37 +12:00</small>	03/10/2018
Phil Healey		03/10/2018

July 2015



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Postgraduate Studies Office  
 Student and Academic Services Division  
 Wahanga Ratonga Matauranga Akonga  
 The University of Waikato  
 Private Bag 3105  
 Hamilton 3240, New Zealand  
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Chapter 5 (Study B) - Short-term effect of training and competition on muscle soreness and neuromuscular performance in elite rugby athletes.

Tavares F., Healey P., Smith TB., Driller, M. (2018). The effect of training load on neuromuscular performance, muscle soreness and wellness during an in-season non-competitive week in elite rugby athletes. The Journal of Sports Medicine and Physical Fitness. Epub ahead of print

Nature of contribution by PhD candidate	Development of study design, data collection and analysis, manuscript preparation and journal submission.
Extent of contribution by PhD candidate (%)	90

### CO-AUTHORS

Name	Nature of Contribution
Matthew Driller	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript
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Brett Smith	 <small>Digitally signed by Brett Smith DN: cn=Brett Smith, o=University of Waikato, ou=Sport and Leisure Studies Dept, email=b.smith@waikato.ac.nz Date: 2018.10.10 10:44:22 +1200</small>	03/10/2018
Phil Healey		03/10/2018

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Postgraduate Studies Office  
 Student and Academic Services Division  
 Wahanga Rātonga Mātauranga Akonga  
 The University of Waikato  
 Private Bag 3105  
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Chapter 6 – The effects of chronic cold water immersion in elite rugby players. International Journal of sports physiology and performance.

Tavares, F., Beaven, M., Teles, J., Baker, D., Healey, P., Smith, T. B., Driller, M. (2018). The effects of chronic cold water immersion in elite rugby players. International Journal of sports physiology and performance. Epub ahead of print

Nature of contribution by PhD candidate: Development of study design, data collection and analysis, manuscript preparation and journal submission.

Extent of contribution by PhD candidate (%): 85

### CO-AUTHORS

Name	Nature of Contribution
Matthew Driller	Supervision of all stages (study design, data collection and analysis) and critical revision of the manuscript
Brett Smith	Support of all stages (study design, data collection and analysis) and critical revision of the manuscript
Júlia Teles	Support with data analysis
Phil Healey	Support with data collection and development of study design
Dan Baker	Support with data collection and contribution to drafting of the manuscript.
Martyn Beaven	Support to study design, data analysis, hormonal analysis and contribution to drafting of the manuscript.

### Certification by Co-Authors

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Name	Signature	Date
Matthew Driller		03/10/2018
Brett Smith		03/10/2018
Júlia Teles		03/10/2018
Phil Healey		03/10/2018
Dan Baker		03/10/2018
Martyn Beaven		03/10/2018

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Postgraduate Studies Office  
 Student and Academic Services Division  
 Wahanga Ratonga Matauranga Akonga  
 The University of Waikato  
 Private Bag 3105  
 Hamilton 3240, New Zealand  
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Chapter 7 - Practical applications of water immersion recovery modalities for team sports.

Tavares, F., Walker, O., Healey, P., Smith, T. B., Driller, M. (2018). Practical applications of water immersion recovery modalities for team sports. *Strength & Conditioning Journal*, 40(4):48-60.

Nature of contribution by PhD candidate: Analysis of literature, manuscript preparation and journal submission.

Extent of contribution by PhD candidate (%): 90

### CO-AUTHORS

Name	Nature of Contribution
Matthew Driller	Supervision of all stages and critical revision of the manuscript
Brett Smith	Critical revision of the manuscript
Phil Healey	Critical revision of the manuscript
Owen Walker	Support of all stages and critical revision of the manuscript

### Certification by Co-Authors

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Phil Healey		03/10/2018
Owen Walker		03/10/2018

July 2015