The Application of Recovery Strategies for Cyclists

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Abstract

During training and congested competition schedules, recovery strategies are thought to alleviate post-exercise fatigue and enhance subsequent performance. Consequently, a substantial challenge is placed on athletes and coaches to ensure optimal recovery is attained, this has been one of the contributing factors for the development of acute recovery strategies aimed to enhance performance recovery. Recently, athletes have incorporated the use of Intermittent Sequential Pneumatic Compression (ISPC), a form of dynamic compression, to enhance recovery post-exercise. However, with contrasting findings and limited literature, further research is necessary to determine the value of ISPC on exercise recovery and/or subsequent performance. While ISPC has been examined in cycling settings, studies have failed to examine the effects of this strategy in trained cyclists, limiting the ecological validity of their results. Furthermore, the Omnium is a multi-race event in track cycling at the Olympic Games, with short periods of recovery (as little as 30-mins) between 6 separate races. Therefore, the objective of this investigation was to examine the impact of ISPC on trained cyclists, when implemented between a maximal 20-min cycling bout (simulated scratch race) and a 4-min maximal test (simulated individual pursuit), as experienced during an Omnium track cycling competition. Twenty-one (13 male, 8 female, mean ± SD; age: 36 ± 14 years) trained cyclists completed a familiarisation trial followed by two experimental trials in a counterbalanced, crossover design. Participants performed a fixed-intensity 20-min cycling bout on a Wattbike cycle ergometer, followed by a 30-min recovery period where ISPC recovery boots or passive recovery (CON) was implemented. At the conclusion of the recovery period, participants performed a 4-min maximal cycling bout (4-minTT). Average power (Watts) for the 4-minTT, blood lactate concentration (BLa) and perceived total quality recovery (TQR) during the recovery period were used to examine the influence of ISPC.

There were no significant differences between trials for the 4-minTT ($p = 0.08$), with the effect deemed to be *trivial* ($d = -0.08$). There was an *unclear* effect (d ±90%CI = 0.26 ±0.78, $p = 0.57$) for ISPC vs CON in the clearance of BLa during the recovery period. There was a *small* but not significant difference for TQR in favour of ISPC (d ±90%CI = 0.27 ±0.27, $p = 0.07$). These findings suggest there is little additional benefit associated with the use of ISPC to enhance recovery and subsequent performance when used during the recovery period between two events in a simulated Omnium track cycling competition.

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List of Abbreviations

+ : positive/enhanced

20-min TT : maximal 20-min cycling bout

4-min TT : 4-min maximal cycling bout

AE : arm exercise

AR : active recovery

ARW : active recovery in water

ATP : adenosine triphosphate

BLa : blood lactate concentration

BMX : bicycle motocross

Ca^{2+} : calcium ion

CCT : cold compression therapy

CCWI : continuous cold water immersion

CK : creatine kinase

CNS : central nervous system

- : negative/detrimental

= : no change

COMP : compression garment/full length tights

CON : control condition/passive rest

CRP : c-reactive protein

CS : compression stockings

CV : coefficient of variation

CWI : cold water immersion

CWT : contrast water therapy

EMG : electromyography

EMS : electromyostimulation/electronic muscle stimulation

ES : effect size

Ex : exercise bout

GH : growth hormone

GSH	:	reduced glutathione
GSSG	:	oxidised glutathione
H^+	:	hydrogen ion
H_2PO_4-	:	monovalent phosphate
HR	:	heart rate
HR_{max}	:	maximum heart rate
HRV	:	heart rate variability
HUM	:	humidification therapy
HWI	:	hot water immersion/therapy
ICC	:	intraclass correlation coefficient
ICWI	:	intermittent cold water immersion
IGF-1	:	insulin-like growth factor 1
IL-6	:	interleukin 6
IP	:	individual pursuit
ISPC	:	intermittent sequential pneumatic compression
K^+	:	potassium ion
LnHF	:	natural logarithm of high frequency power density
MB	:	mountain biking
Min	:	minute
MU	:	motor unit
MVIC	:	maximum voluntary isometric contraction
N	:	number of cyclists
n/a	:	not measured/not applicable
No sig dif	:	no statistically significant difference
PCO_2	:	partial pressure of carbon dioxide
PCr	:	phosphocreatine
pH	:	potential of hydrogen
Pi	:	inorganic phosphate
PO_2	:	partial pressure of oxygen
PPO	:	peak power output
PRL	:	passive recovery on land
PRW	:	passive recovery in water

QR : quiet rest

rh : relative humidity

rMSSD : natural logarithm of the square root of mean squared differences of successive R-R intervals

RoM : range of motion

RPE : rating of perceived exertion

RPM : cycling revolutions per minute

SD : standard deviation

Sec : seconds

SM : sports massage

SMVIC : maximum voluntary isometric contraction with superimposed electrical stimulation

SR : scratch race

SS : static stretching

tDCS : transcranial direct current stimulation

T_{mus} : muscle temperature

TQR : perceived total quality recovery

T_{re} : rectal temperature

T_{sk} : skin temperature

TT : cycling time trial

TWI : thermoneutral water immersion

VAS : visual analogue pain scale

VO_2 : oxygen uptake

VO_{2max} : maximal oxygen uptake

W : watts

W/Kg : watts per kilogram of bodyweight

WAnT : wingate anaerobic cycling test

Watts : average power

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Publications Arising from this Thesis

The following publications have arisen directly from this thesis:

Chapter Two:

Overmayer, R. G., & Driller, M. W. (2017). Pneumatic compression fails to improve performance recovery in trained cyclists. *International Journal of Sports Physiology and Performance*, 1-21.

Chapter One:

Overmayer, R., Tavares, F., & Driller, M. (2017). Acute post-exercise recovery strategies in cyclists. (Under Review).

The following is a publication that has arisen during this candidature:

Appendix Seven:

Driller, M. W., & Overmayer, R. G. (2017). The effects of tissue flossing on ankle range of motion and jump performance. *Physical Therapy in Sport*, *25*, 20-24.

Thesis Overview

The current thesis is comprised of three chapters. Chapter one contains a review of literature and introduces the reader to post-exercise recovery strategies in cycling. Chapter two focuses on an original investigation examining a novel post-exercise recovery strategy in cyclists; termed ‘Intermittent Sequential Pneumatic Compression’. Chapter three provides recommendations for future recovery research in cyclists. Both chapter one and chapter two, are presented in the style of individual journal articles.

Chapter One:

Acute Post-Exercise Recovery Strategies in Cyclists:

A Literature Review

Introduction

There are many disciplines in professional cycling such as track cycling, road cycling, mountain biking and bicycle motocross (BMX).[1-3] Road cycling can be considered one of the most arduous sports, with professional cyclists training one or more times per day, for durations of up to 5 hours per training session and 6-8 times per week.[1, 4] Furthermore, the Tour De France is a road cycling stage race, considered one of the most difficult sporting endurance competitions, with riders competing at average speeds >40kph, up to 5 hours per day, over three weeks.[5] Additionally, many of the cycling disciplines involve multiple races a day or racing over consecutive days.[3, 4, 6] During training and congested competition schedules, recovery strategies are thought to alleviate post-exercise fatigue and enhance subsequent performance.[7, 8] Consequently, a substantial challenge is placed on athletes and coaches to ensure optimal recovery is attained, and has been one of the contributing factors for the development of novel recovery strategies to enhance performance.[8, 9] The main purpose of this review is to summarize the scientific literature on acute post-exercise recovery strategies, implemented in the sport of cycling.

Literature Search

Based on a search of Google Scholar, SPORTDiscus, Web of Science, MEDLINE/PubMed and Cochrane databases, to our knowledge, there is currently no published review examining the literature on recovery strategies used with cyclists as the participants of interest. The relevant literature for this review was obtained from a search within the Google Scholar, MEDLINE/PubMed, SPORTDiscus, Web of Science and Cochrane databases. Included terms for the searches were: “Recovery strategies cyclists/cycling”, “cold water immersion cyclists/cycling”, “active recovery cyclists/cycling”, “electromyostimulation cyclists/cycling”, “massage recovery cycling/cyclists”, “compression recovery cyclists/cycling”, “compression garments recovery cycling/cyclists”, “cryotherapy cyclists/cycling”, “water immersion recovery cyclists/cycling”, “hydrotherapy recovery cyclists/cycling”, “static stretching recovery cyclists/cycling”, “dynamic stretching recovery cyclists/cycling”, “ice cyclists/cycling”, “sequential intermittent pneumatic compression cyclists/cycling”, “dynamic compression cyclists/cycling”, “intermittent pneumatic compression cyclists/cycling”. The inclusion criteria was limited to the English language and studies published prior to August 2017. Twenty-seven studies were included for analysis. Recovery strategies examined include active recovery (AR), sports massage (SM), cold water immersion (CWI), compression garments (COMP), electromyostimulation (EMS), humidification therapy (HUM), passive recovery in water (PRW), active recovery in water (ARW), static stretching (SS), contrast water therapy (CWT), compression stockings (CS), hot water immersion/therapy (HWI), cold compression therapy (CCT) thermoneutral water immersion (TWI) and a combination of active recovery and sports massage.

Fatigue in Cycling

In order to discuss the potential fatigue mechanisms associated with cycling, one must first determine the duration of the event.[10] For example, while the winning time for the men’s Omnium flying lap race at the 2016 Rio Olympics was 12.506s, the winning time for the road race was 6:10:05s; resulting in a variance in exercise intensity, energy utilization and associated fatigue.[1, 11] Therefore, cycling events have been categorized with race duration (table 1). The following chapter provides a general overview of fatigue associated with the category durations provided.

Table 1. Men's Cycling Events Categorised According to Duration.

Category	**Duration**	**Events**
Sprint	0 – 15 sec	Track Omnium Flying Lap (12.51s)*
Short-duration	30 – 60 sec	Track Team Sprint (42.44s)* BMX (34.64s)* Track Omnium 1-km TT (60.92s)*
Middle-duration	2 min – 18 min	Track Keirin (2:27s submaximal + 34s sprint)* Track Omnium IP (4:14.98s)* Track Team Pursuit (3:50.27s)* Track Omnium Elimination (Approx. 13:49s submaximal with sprint bursts)* Track Omnium SR (17:24s)*
Endurance	Over 45 min	Track Omnium Points Race (46:23s)* Road Race (6:10:05s)* Road Individual TT (1:12:15.42s)* Cross-Country MB (1:33:28s)*

Sec second, *min* minute, *TT* time trial, *IP* individual pursuit, *SR* scratch race, *BMX* bicycle motocross, *MB* mountain biking. *Based on 2016 Rio Olympic men's winning times.

Fatigue During Sprint Cycling

Humans only have Adenosine Triphosphate (ATP) reserves for ~2 seconds of maximal contraction,[12, 13] Since ATP serves as the currency for the production of mechanical work, one can expect that a reduction in ATP leads to a state where the capacity to produce mechanical work is reduced.[12] In a brief event such as sprint cycling (i.e. 200m track sprint), energy production is highly dependent on the anaerobic glycolytic system.[1] For example, during a 200m track sprint, the alactic and anaerobic glycolytic systems contribute 40 and 55% of energy production, respectively.[1] Therefore, performance decrements in these events have been attributed to a combination of 'peripheral metabolic' and 'central/neural' mechanisms.[10, 14] Peripheral metabolic mechanisms are associated not only to a breakdown of phosphocreatine (PCr) and a subsequent increase in inorganic phosphates (Pi), but also to a reduction in cross-bridge cycling and force production.[15] Neural mechanisms include a reduction of the central nervous system (CNS) to drive motor neurons; therefore decreasing the number of active motor units (MU), including those innervating fast twitch muscle fibres, responsible for maximal force production.[14, 16] Thus, a reduction in the capability to recruit fast twitch MU, will ultimately result in a reduction of power output during sprint cycling.[14]

Fatigue During Short-duration Cycling

During short-duration events (table 1), the anaerobic and aerobic systems contribute to the vast majority of energy production.[1] For example, during a female 500m cycling sprint (duration ~35s), the anaerobic glycolytic and aerobic contribution is suspected to be 45 & 35%, respectively.[1] Moreover, the anaerobic glycolytic and aerobic contribution during a male 1000m track cycling event (duration ~60s) is suspected to be 40 & 50%, respectively.[1] Conversely, the alactic system is believed to only contribute 10-20% of total energy production during events of this duration.[1] The dependency on the anaerobic glycolytic system, is associated with an increase in metabolites and therefore a loss of muscle function.[17-19] While traditionally thought that increased H^+ was the main metabolite which contributed to fatigue,[17] Degroot and colleagues[20] have revealed that an increase in Pi and monovalent phosphate ($H_2PO_4^-$), are better correlated with a reduction in maximum voluntary contraction than H^+. An extensive review on the effects of metabolism end products and acidosis on muscle fatigue can be found elsewhere.[17-19] Alike with sprint cycling, a reduction in the capability to recruit fast twitch MU due to CNS fatigue, will ultimately result in a reduction of power output during short-duration cycling.[14]

Fatigue During Middle-duration Cycling

Middle-duration events in cycling range from a duration of between 3 to 18-mins (table 1). Therefore, the metabolic contribution from these events are highly dependent on the anaerobic glycolytic and aerobic system, with a minor contribution from the alactic system (~1%).[1] For example, in the male 4-km TT (~4 min duration) the anaerobic glycolytic system contributes 14% of energy production, while the aerobic glycolytic system contributes a greater 85% of energy production.[1] As a result of the high aerobic demand of cycling within this category, a limiting factor of performance is the ability of the cardiovascular system to supply sufficient oxygen to the working muscle.[21] Middle-duration events occur on the severe intensity domain where power outputs are generated above critical power (CP) and sustained until VO_{2max} is achieved.[22] Performing above CP during cycling tasks has been linked to a reduction of muscle PCr, potential of hydrogen (pH), ATP and a concomitant increase in P_i, plasma potassium ion (K^+) and blood and muscle lactate.[11] A reduction in PCr and ATP concentration has been associated with an increase in electromyography (EMG) signals, demonstrating an attempt of the CNS to compensate for increased peripheral fatigue.[11] Moreover, a rise in extracellular K^+ will result in a decrease of action potential conduction, leading to a reduction of calcium ion (Ca^{2+}) release from the sarcoplasmic reticulum and a loss of contraction force.[23] An increase in plasma K^+ content has been correlated with an increase in neural drive (r=0.64); believed to be a strategy to maintain power output production.[11] For the aforementioned reasons, fatigue during cycling within middle-durations can be associated to metabolic depletion (PCr and ATP), metabolite accumulation (P_i, plasma K^+ and blood and muscle lactate) and neuromuscular fatigue (increased CNS activity).

Fatigue During Endurance Cycling

Endurance cycling events range from approximately 45-mins to ~6-hrs (table 1). Numerous models to explain fatigue during cycling within this category include but are not limited to; the energy depletion, metabolite accumulation, muscle trauma and neuromuscular fatigue models, and the reader is directed to an extensive review conducted elsewhere.[21] Given the duration of these events, energy is predominantly produced from the aerobic system.[1] Alike with middle-duration cycling and due to the high aerobic demand of this category, a limiting factor of performance is the ability of the cardiovascular system to supply sufficient oxygen to the working muscle.[21] Furthermore, metabolic disturbances include a reduction in PCr, ATP, pH and glycogen, with a concomitant increase in blood and muscle lactate and K^+;

believed to disrupt Ca^{2+} release and result in a loss of contraction force.[11] Additionally, prolonged endurance cycling results in a severe depletion of liver and muscle glycogen[11, 21] and reductions in voluntary strength.[24] A further explanation for an increase in fatigue and consequent reduction in power output could be mechanical damage, resulting from muscle cell disruption.[25] Alterations of neuromuscular functions during prolonged cycling exercise has been reviewed elsewhere.[24] Therefore, fatigue during endurance cycling is highly complex and multifaceted, categorized by a series of afferent feedback mechanisms, designed to protect a cyclist from overexerting, otherwise leading to injury or death.[21]

Recovery Modalities in Cycling

Compression Garments (COMP)

Compression garments, or static compression, are thought to improve exercise recovery through the application of pressure at the extremity i.e. ankle, thereby enhancing venous blood flow, cardiac output and stroke volume which in turn, assists in the removal of metabolic waste accumulated as a result of exercise.[8] There are two types of static compression that have been examined in cycling literature: Compression stockings[6, 26] and full-length tights.[8, 27] The ability of static compression to improve subsequent performance, perceived muscle soreness and muscle swelling, appears to be irrespective of garment type and pressure exerted, with both compression stockings and full-length tights, shown to attenuate the decrement in mean and max power, decrease thigh girth, calf girth and perceived muscle soreness, post-recovery when compared with a passive control (table 3).[6, 8, 26, 27] However, it is worth noting, that not all studies quantified the actual pressure exerted by the garments used (table 2). Menetrier and colleagues[6] discovered an increase in subsequent performance mean power of 1.8 ± 1.0% during 5-mins of maximal cycling, from the use of compression stockings for 12-mins during recovery when compared with a passive control. Full length tights and compression stockings used for 12-80mins have been shown to improve the rate of BLa removal following 10-min cycling beginning at 80% and increasing to 90% PPO, 30-min cycling beginning at 70% and increasing to 100% PPO and 5-mins of maximal cycling.[6, 26, 27] However, full length tights were no more beneficial than passive rest alone, at reducing BLa concentration following 30s of maximal sprint cycling.[8] Furthermore, COMP resulted in no change in HR measures, TQR or RPE when compared with a control.[6, 8, 26] It should not be discounted that a psychological advantage by means of a placebo effect is responsible, at least in part, for the resultant performance benefits. A study by Argus and colleagues[8] attempted to control for a placebo effect through use of a belief questionnaire. Participants were required to predict whether or not the recovery intervention would enhance their recovery and results revealed that only 2/8 participants accurately predicted the best strategy. Therefore indicating that a placebo effect may not be responsible for the resultant performance benefits associated with COMP. While it is unclear whether a biochemical mechanism is responsible for improved recovery and performance from the use of COMP, it is evident that there is a correlation between a reduction in muscle swelling and perceived soreness and a consequent enhancement or maintenance of subsequent mean and maximal cycling power, and COMP proves to be a worthwhile addition to the cyclists/coaches recovery toolbox.

Future research should continue to use a valid and reliable method of pressure monitoring such as the Kikuhime[28] to continue to examine whether there is a relationship between pressure exerted and resultant benefits in cyclists. To better understand whether a placebo effect is responsible for the benefits associated with COMP, researchers should continue to use a visual analogue scale[29] to examine 'belief'.

Table 2. Pressure Exerted by Compression Garment Type and Reporting Method.

Author	Garment Type	Calf Compression (mmHg)	Thigh Compression (mmHg)	Reporting method
Argus et al., 2013[8]	Full length tights	27 ± 6	18 ± 2	Kikuhime
Driller & Halson, 2013[27]	Full length tights	20.5 ± 3.1	11.8 ± 2.6	Unpublished observations
Chatard et al., 2004[26]	Compression stockings	18	12	Manufacturer report
Ménétrier et al., 2013[6]	Compression stockings	27	14	Manufacturer report

Table 3. Summary of Studies Examining the Use of Compression Garments Post-exercise in Cyclists.

Study	**Sample/ Training Status/ Sample Size**	**Exercise Protocol**	**Recovery Strategy & Duration**	**Markers of Recovery/ Performance**	**Results**	**Overall**
Argus et al, 2013[8]	Highly trained cyclists (A/B grade) N = 11	Pre: 30s max sprint cycling (S1) with 60s preload @ 4.5W/Kg Post 1 (S2) & Post 2 (S3): 30s max sprint cycling with 60s preload @ 4.5W/Kg	COMP (calf: 27 ± 6 mmHg; thigh: 18 ± 2 mmHg) EMS (15.7 ± 2.8 Hz) HUM Passive (CON) Duration: 2 x 20-mins between bouts (R1 & 2)	30s cycling mean power BLa TQR Belief	COMP attenuated ↓ mean power vs CON S1 – S2 (0.8 ± 1.2 %, *possibly beneficial*) & S1 – S3 (1.2 ± 1.9 %; *possibly beneficial*) HUM attenuated ↓ mean power vs CON from S1 – S3 (2.2 ± 2.5 %, *likely beneficial*) COMP no sig dif BLa or TQR vs CON ($p > 0.05$) HUM & EMS ↓ R2 BLa vs CON (HUM: 4.3 ± 7.9 %, *possibly beneficial*, EMS: 4.9 ± 6.9 %, *possibly beneficial*) EMS ↑ R2 TQR vs CON (0.7 ± 0.9, *likely beneficial*) 2 / 8 participants accurately predicted which strategy would enhance their recovery (belief).	COMP & HUM > CON attenuating ↓ mean power COMP & CON = BLa & TQR HUM & EMS > CON ↓ BLa EMS > CON ↑ TQR Possibly no placebo effect (2/8 belief)

Driller & Halson, 2013[27]	Highly trained cyclists (VO_{2max} = 66.6 ± 3.8 $mL \cdot Kg^{-1} \cdot min^{-1}$; A/B grade) N = 10	Pre & post: 30-min cycling (15-min 70% PPO & 15-min maximal TT)	COMP (calf: 20.5 ± 3.1 mmHg; thigh: 11.8 ± 2.6 mmHg Loose fitting shorts (described as CON) Duration: 60-mins	30-min cycling mean power Thigh girth Calf girth BLa Perceived muscle soreness	COMP attenuated ↓ mean power vs CON (COMP: -0.20 % / CON: -2.15 %; ES: 0.21, *small*; $p < 0.05$) COMP ↓ thigh girth vs CON (ES ±90%CL: -0.9 ±0.6, *trivial*, $p < 0.05$) COMP ↓ calf girth vs CON (-1.0 ±0.7, *trivial*, $p < 0.05$) COMP ↓ BLa vs CON (-26.1 ±17.9, *moderate*, $p < 0.05$) COMP ↓ perceived muscle soreness vs CON (ES: -0.62, *moderate*, $p > 0.05$)	COMP > CON attenuating ↓ mean power COMP > CON ↓ thigh and calf girth, BLa & perceived muscle soreness
Chatard et al, 2004[26]	Trained elderly cyclists (VO_{2max} = 49 ± 6 $mL \cdot Kg^{-1} \cdot min^{-1}$; mean age = 63 years; training years = 10 ± 4 years) N = 12	Pre & post: 5-min max cycling	CS (calf: 18 mmHg; thigh: 12 mmHg) Passive without CS (CON) Duration: 80-mins	5-min cycling max power HR BLa & hematocrit RPE	CS attenuated ↓ max power vs CON (2.1 ± 1.4 %, $p < 0.01$) CS no sig dif for HR post-recovery or RPE vs CON ($p > 0.01$) CS ↓ BLa and hematocrit during recovery vs CON (BLa: $F = 7.7$, haematocrit: $F = 6.8$, $p < 0.01$)	CS > CON attenuating ↓ max power CS > CON ↓ BLa and hematocrit during recovery CS & CON = HR, and RPE

Menetrier et al, 2013[6]	Competitive male cyclists (PPO = 5.0 ± 0.2 W/Kg) N = 12	Pre: 10-min cycling (5-mins 80% PPO & 5-mins 90% PPO Post: 5-min maximal cycling	Passive seated [~21 °C, ~30% rh] (CON) CWT (4 x 3-min to top thigh; 1-min cold bath [10-12°C], 2-min hot bath [36-38°C], 5s changeover) CS (according to manufacturer: calf = 27mmHg; thigh = 14mmHg) Duration: 1.5-mins passive seated pre and post condition 12-mins per condition	5-min maximal cycling mean power BLa Perceived muscle soreness HR RPE	CWT ↑ mean power vs CON (368 ± 12 W, +4.1 ± 0.7 %; $p < 0.001$) CS ↑ mean power vs CON (361 ± 15 W, +1.8 ± 1.0 %; $p < 0.05$) CWT ↑ mean power vs CS (+2.2 ± 0.8 %; $p < 0.05$) CWT & CS ↓ BLa vs CON (CWT: 5.7 ± 1.0 $\text{mmol}\cdot\text{L}^{-1}$; $p < 0.001$, CS: 7.3 ± 1.2 $\text{mmol}\cdot\text{L}^{-1}$; $p < 0.05$ / CON: 8.4 ± 1.0 $\text{mmol}\cdot\text{L}^{-1}$) CWT ↓ BLa vs CS ($p < 0.05$) CWT & CS ↓ perceived muscle soreness vs CON (CWT: 1.1 ± 0.5 au; $p < 0.001$ / CS: 1.6 ± 0.4 au; $p < 0.001$ / CON: 3.2 ± 0.5 au) HR during exercise & RPE no sig dif between conditions ($p > 0.05$)	CWT & CS > CON ↑ mean power CWT > CS ↑ mean power CWT & CS > CON ↓ BLa CWT > CS ↓ BLa CWT & CS > CON ↓ perceived muscle soreness CWT, CS & CON = HR during exercise and RPE

N number of cyclists, *W/Kg* watts per kilogram of bodyweight, *COMP* compression garment/full length tights, *EMS* electromyostimulation/electronic muscle stimulation, *HUM* humidification therapy, *CON* control condition/passive rest, *BLa* blood lactate concentration, *TQR* perceived total quality recovery, VO_{2max} maximal oxygen uptake, *PPO* peak power output, *TT* cycling time trial, *CS* compression stockings, *rh* relative humidity, *HR* heart rate, *RPE* ratings of perceived exertion, *CWT* contrast water therapy.

Cold Water Immersion (CWI)

Cold water immersion is the most researched recovery strategy in cycling literature (table 4). Athletes exercising in the heat are advised to maintain a narrow core temperature of between 37-39°C to optimise performance; a rise of core temperature beyond 39°C can result in increased perceived fatigue, a reduction in exercise performance and premature exercise termination.[30, 31] CWI has also been suggested beneficial for the treatment of inflammation and perceived pain.[32] When using CWI to mitigate hyperthermia, it would be assumed that longer immersion durations may be beneficial. However, 5-mins of CWI was just as effective at reducing core temperature when compared to 10 and 20-mins.[33] The same authors speculate that involuntary contraction from shivering due to longer durations (10-mins or more) in cold water, leads to increased metabolic heat development. Due to the large number of studies examining CWI in cyclists, performance recovery and physiological variables will be examined separately for this recovery modality.

Cold Water Immersion for Performance Recovery

When considering the use of CWI for cycling performance, there are five common variables examined a) Power (peak power output, mean power output) b) Time (time to completion, exhaustion or PPO) c) Total work performed d) Isokinetic/isometric muscular contraction (maximum voluntary isometric contraction, isokinetic/isometric torque).

Power

Three studies have reported improvements in power measures[9, 30, 34] while a further six studies report no significant difference following CWI.[9, 35-39] However, one of these studies failed to utilise a control group in their design.[39] Only one study reported CWI as detrimental to power output.[40] During a 4-km TT in the heat (35°C), power output was reduced by 20 ± 6% in a control condition, where CWI was able to attenuate this decrement to only a 3 ± 3% reduction in power output.[30] During 66 ramped sprints beginning at 5s and working up to 15s per sprint, CWI was able to improve sprint power measures over 3 days when compared with a control (within-trial change mean ± 90%CL, CWI: +2.4 ±2.3 % vs CON: -9.6 ±5.0 %).[9] This improvement in both time trial and sprint performance was further supported by Vaile and colleagues[34] who used the same sprint protocol as the aforementioned study and revealed up to a 1.4% increase in mean power over 5 days and a better maintenance of power when compared with a control on days 4-5 ($p < 0.01$). During a 9-min TT comprised of 2 x 2-min TT's and 1 x 5-min TT, CWI improved mean power by up to 1% over 5 days, where the control condition reduced power by up to 3.8% over the same 5 day period.[34] In the studies exhibiting no improvement in power output from CWI, two studies utilised the same recovery protocol, which included 5-mins of the condition and a further 15-mins passive seated.[35, 36] Further studies had extensive recovery durations which may have diluted the impact of the recovery intervention such as the study by Christensen & Bangsbo,[37] who used CWI for 15-mins and then followed this with a 2h 35m rest period. Stanley and colleagues[38] had a similarly long protocol, using CWI for 5-mins and then followed this with 2h 45m passive rest. Additionally, in a later study by Stanley and colleagues[9] the authors reported no improvement in power during cycling time trials. However, these time trials were preceded by 66 ramped sprints, from which they saw CWI attenuated sprint power by up to 12% over 3 days when compared with a control; perhaps if the order of events were rotated in this study, an effect would have been observed. In the one study that revealed CWI was detrimental to performance,[40] participants were required to push a very large gear, using a 53 tooth chainring and a 13 tooth rear sprocket, totalling 110 inches per cycle revolution, in a short duration of 30s and participants were confined to this one gear. This may have led to participants being unable to overcome the resistance effectively, while other participants could have found this resistance easier, especially considering there was a 9.9kg deviation in weight and the level of experience varied among riders (category rank, training miles per year and races per year). Additionally, studies that examined subsequent performance and reported benefits from the use of CWI had an acclimation period consisting of a significant warm-up[34] or 10-mins passive rest post CWI,[30] where Schniepp and colleagues[40] required participants to towel dry and immediately remount their bicycles. Indeed, it has been suggested that a reduction in muscle temperature can impair cross-bridge cycling, motor unit activation and enzyme activity rate[40] which perhaps is mitigated by the use of passive rest or a warm-up post condition.

Time

CWI used for 5-mins (14°C) and with 10-mins passive rest pre & post CWI, was able to improve 4-km TT time to completion in the heat (35°C, 40% rh) by 18 ± 11.5 seconds.[30] However, increasing the passive rest duration from 10 to 15-mins post CWI, despite using the same water temperature (14°C) was unable to improve 1-km TT time to completion performance in the same environmental conditions in two studies.[35, 36] Stanley and colleagues [38] also reported no significant difference in time to completion however, as alluded to previously, authors required participants to rest extensively (2h 45m) before completing their performance trial which would have diluted the impact of the recovery intervention.

Total work performed

Three studies improved total work performed when using CWI.[31, 32, 34] Following 66 max sprints and a 9-min TT, CWI (15°C) used for 14-mins over 5 consecutive days improved TT total work performed on days 4 & 5 ($p < 0.05$); with a 5 kJ improvement in mean TT total work on the 5th day.[34] Furthermore, while no passive rest control condition was examined, CWI (15°C) used for 15-mins and followed by 40-mins passive rest, improved total worked performed; while AR (40% PPO) resulted in a reduction of total work performed (CWI: +0.10 ± 0.7%, AR: -1.8 ± -1.1%).[32] In an earlier study by Vaile and colleagues[31] CWI was again superior when compared to AR and maintained 30-min cycling total work between bouts while AR decreased total work by 4.1 ± 1.8 % ($p = 0.00$). Only one study revealed no significant difference in total work performed from the use of CWI[41] and can be attributed to a long recovery duration consisting of 25-mins passive rest, 20-mins per condition and a further 45-mins passive rest (total = 1.5h) before the performance trial.[41]

Isokinetic/Isometric muscular contraction

CWI's impact on isometric and isokinetic force production following cycling is confounding. Peiffer and colleagues[41] revealed that maximum voluntary isometric contraction was reduced from the use of CWI 45 & 90-mins post 16.1km TT when compared to a passive control. In this study, authors compared the use of electrical stimulation to examine if central inhibition was the limiting factor however, as results revealed no significant difference between maximum voluntary isometric contraction and maximum voluntary isometric contraction with superimposed electrical stimulation ($p < 0.05$), it was suggested that the limiting factor was related to a reduction in blood flow as examined by a reduction in venous vessel diameter 90-mins post TT. Furthermore, later studies by the same author[33, 35] revealed no significant difference in isometric and isokinetic torque.

Cold Water Immersion for Recovery

When compared with a passive seated control, CWI decreased HR post-recovery by 4.2 % when used for 15-mins between sprint cycling of 30s[40] and also reduced HR overtime (post-exercise to 40-mins post-exercise) by 10 b·min^{-1}[42]. On day one of a three day protocol, CWI also significantly decreased HR post-recovery.[9] In addition to improved HR post-recovery, CWI consistently increased HRV measures with *large* effect sizes.[9, 36, 38]

Perceived recovery measures revealed that CWI improved ratings of perceived physical and mental recovery, reduced perceived muscle soreness and perceived general fatigue.[36, 42] Stanley and colleagues[38] also revealed similar improvements in a reduction of perceived general fatigue, leg soreness and an increase in physical recovery however, no significant difference was observed in mental recovery. This trend also occurred in a later study by the same author[9] who observed a reduction in perceived leg soreness from CWI however, perceived mental recovery and perceived tiredness were *unclear* between conditions. Christensen and Bangsbo[37] was the only study to examine perceived readiness and results revealed there was no change between conditions.

T_{re} was reduced post-recovery by 0.4°C,[30] 40-mins post-exercise (CWI: $\Delta 1.99 \pm 0.50$ °C, CON: $\Delta 1.49 \pm 0.50$ °C, $p = 0.01$),[42] 2.5-3% 80-mins post-exercise[33] and a statistically significant reduction was observed 90-mins post-exercise.[41] Surprisingly and alike with HR, Buchheit and colleagues[36] reported no significant difference when CWI was used 20-mins between 1-km maximal cycling in the heat. This was further supported by Peiffer and colleagues[35] who used the same exercise protocol and recovery duration. Furthermore, CWI was ineffective at reducing T_{re} when used for 14-mins following 66 max sprints and a 9-min TT.[34] In the one study that compared body temperature between CWI and a control,[42] results indicated that following a 40-min TT and 20-mins passive rest in the heat (34.3 ± 1.1°C, 41.2 ± 3.0% rh), CWI used for 3 x 60s with 2-mins seated rest in ambient temperatures between immersion, reduced mean body temperature post-exercise to 40-mins post-exercise (CWI: -6.3 %, CON: -3.8 %, $p < 0.05$). In addition to a reduction in body temperature, CWI has been shown to reduce T_{mus} 45-mins post a time to exhaustion test in the heat[33] and following a 1-km cycling TT in the heat.[35] T_{sk} was also reduced from the use of CWI post-exercise to 40-mins post-exercise (CWI: -20.2 %, CON: -3.7 %, $p < 0.05$).[42]

BLa results are difficult to interpret as no significant difference ($p = 0.11$) was observed following a 4-min TT[37] however, performance was also not improved in the current study and when CWI was used following a 40-min TT in heat,[42] BLa again revealed no significant difference however, subsequent performance was not examined.

Road cycling events result in short resting durations and in events such as stage races, the resting location is not always the same.[39] Therefore, CWI is not always practical as it would require a movable immersion pool and as a result, Chan and colleagues[39] have examined the use of a dynamic form of cold compression (Game Ready; CoolSystems, Concord, CA, USA). However, results indicated that the device was no more beneficial than AR or CWI at attenuating mean power, RPE or HR following 30-mins cycling comprised of 15-mins at 75% PPO and a 15-min maximal cycling TT in the heat (31°C). Furthermore, AR was more beneficial than dynamic cold compression at reducing BLa measures; indicating that the use of an indoor bicycle bike roller to perform AR between events may be more effective than dynamic cold compression for enhancing recovery when an immersion pool is not practical or available.

CWI has been shown beneficial for improving both cycling TT power and reducing time to completion, particularly when used at 14°C for 5-mins. When used at 15°C for 15-mins, CWI has been shown to improve total work performed during cycling TT's and sprints. CWI has also been shown more beneficial than AR at improving total work. While CWI was detrimental to isokinetic and isometric muscle contraction, isometric muscle testing is perhaps not a valid method of performance reporting for cyclists due to the concentric demand of cycling. These performance benefits were associated with a reduction in HR recovery, increased HRV, a reduction in body temperature, T_{mus} and T_{sk} and increased perceived recovery. CWI was not able to improve perceived mental recovery, tiredness or readiness.

To better understand the role of BLa in performance from the use of CWI, future research should explore a subsequent performance bout and examine BLa pre and post recovery. Furthermore, not using a control condition confounds results as benefits can be observed from other recovery modalities and a passive seated control condition is imperative. Recovery durations were too long in some studies and authors should implement recovery durations with greater ecological validity. To avoid limiting the impact of a recovery intervention, cyclists should not be confined to one gear during a performance trial and be allowed to dictate the load. Certainly, the pre-fatiguing exercise protocol can be controlled to ascertain the same level of fatigue in participants, however, the performance trial should not be controlled/limiting.

Table 4. Summary of Studies Examining the Use of Cold Water Immersion Post-exercise in Cyclists.

Study	**Sample/ Training Status/ Sample Size**	**Exercise Protocol**	**Recovery Strategy & Duration**	**Markers of Recovery/ Performance**	**Results**	**Overall**
Peiffer et al, 2007[41]	Well trained male cyclists (age = 27 ± 7 years; VO_{2max} = 61.7 ± 5.0 mL·Kg^{-1}·min^{-1}) N = 10	Pre: 90-mins cycling @ 80% VO_2 (recorded at second ventilatory threshold) Post: 16.1-km maximal cycling TT Pre & Post in heat (32.2 ± 0.7 °C, 55 ± 2.4 % rh)	CWI (14.3 ± 0.2°C, mid sternum level) Passive seated (CON) [24°C, rh not described] Duration: 25-mins passive rest 20-mins per condition 45-mins passive rest	16.1-km TT total work performed (kJ) T_{sk} T_{re} MVIC SMVIC Femoral vein diameter	No sig dif between conditions for TT total work performed, post-exercise T_{sk}, post-exercise T_{re} and post-exercise femoral vein diameter CWI ↓ T_{sk} vs CON 25-90mins post TT CWI ↓ T_{re} vs CON 50-90mins post TT CWI ↓ MVIC & SMVIC vs CON 45 & 90-mins post TT CWI ↓ femoral vein diameter vs CON 45-mins post TT	CWI & CON = TT total work performed, post-exercise T_{sk}, post-exercise T_{re} and post-exercise femoral vein diameter CWI > CON ↓ T_{sk} 25-90mins and T_{re} 50-90mins post TT CON > CWI maintaining MVIC & SMVIC 45 & 90mins post TT and femoral vein diameter 45-mins post TT

Peiffer et al, 2008[30]	Well-trained male cyclists (age = 35 ± 7 years; VO_{2max} = 60.5 ± 4.5 mL·Kg^{-1}·min^{-1}; PPO = 441 ± 32 W) N = 10	Pre & Post: 25-mins constant paced cycling session (254 ± 22 W @ 65% VO_{2max}) and 4-km TT in heat (35°C, 40% rh)	CWI (14°C, mid sternum level) 5-mins + 10-mins passive seated pre and post CWI Passive seated in heat (CON) [35°C, 40% rh] Duration: 15-mins	T_{re} VO_2 25-min constant paced cycling cadence 4-km TT in heat (35°C) time to completion & power output and RPE	CWI ↓ T_{re} vs CON post-recovery (CWI: 38.2 ± 0.2 °C, CON: 38.6 ± 0.5 °C; $p < 0.05$) No sig dif VO_2 between conditions CWI attenuated ↓ cadence vs CON (CWI: 88 ± 6 rpm, CON: 85 ± 7 rpm, $p < 0.05$) CWI ↓ TT time to completion (-18 ± 11.5 seconds, $p < 0.05$) and RPE (CWI: 15 ± 2, CON: 17 ± 1, $p < 0.05$) vs CON CWI attenuated ↓ TT average power output vs CON (CWI: -3.0 ± 3.0 %, CON: -20 ± 6.0%, $p < 0.05$)	CWI > CON ↓ T_{re} post-recovery CWI & CON = VO_2 CWI > CON ↓ time to completion and attenuating ↓ average power output and cadence CWI > CON ↓ RPE
Peiffer et al, 2008[35]	Male cyclists (age = 29 ± 6 years; VO_{2max} = 56.5 ± 5.0 mL·Kg^{-1}·min^{-1}) N = 10	Pre & post: 1-km cycling TT in heat (35 ± 0.3°C, 40 ± 3% rh)	CWI (14°C, mid sternal level) 5-mins + 15-mins passive seated 20-mins passive seated (CON) [35°C, 40% rh] Duration: 20-mins	T_{re} Isokinetic torque T_{mus} PPO Mean power Time to completion	T_{re} and isokinetic quadriceps torque no sig dif post-recovery between conditions CWI ↓ quadriceps T_{mus} (CWI: 36.4 ± 0.8 °C, CON: 37.7 ± 0.3 °C, $p < 0.001$) No sig dif PPO, average power and time to completion between conditions (p = 0.42 to 0.50)	CWI > CON ↓ quadriceps T_{mus} in heat CWI & CON = PPO, average power, time to completion and rectal temperature in heat

Peiffer et al, 2009[33]	Male cyclists (age = 29 ± 3 years; VO_{2max} = 64.0 ± 5.7 $mL \cdot Kg^{-1} \cdot min^{-1}$; PPO = 435 ± 45 W) N = 12	Pre: Cycling time to exhaustion test in heat (40°C, 40% rh, 57 ± 7 % VO_{2max})	CWI x 5-mins (CWI5) [14°C, mid sternum level] CWI x 10-mins (CWI10) [14°C, mid sternum level] CWI x 20-mins (CWI20) [14°C, mid sternum level] Passive seated x 20-mins (CON) [24°C] Duration: 25-mins passive seated (24°C, rh not described) Condition duration above	Time to exhaustion (min) Total work performed (kJ) T_{re} T_{mus} Isometric and isokinetic torque	No sig dif between conditions for time to exhaustion & total work performed CON ↑ T_{re} vs all CWI conditions 75-mins & 80-mins post-exercise CWI ↓ T_{re} 45-80mins post time to exhaustion test (CWI5: -2.8 ± 0.8 %, CWI10: -2.5 ± 0.7 %, CWI20: -3.0 ± 1.1 %, CON: -1.2 ± 0.6 %) CWI ↓ T_{mus} vs CON 45-mins post time to exhaustion test (CWI5: 34.1 ± 1.1 °C, CWI10: 33.2 ± 1.2 °C, CWI20: 32.5 ± 21.1 °C, CON: 36.4 ± 0.7 °C) CWI10 & CWI20 ↓ T_{mus} vs CWI5 immediately post-recovery (CWI5: 35.4 ± 1.4, CWI10: 34.1 ± 1.9 °C, CWI20: 32.5 ± 2.1 °C) No sig dif isometric and isokinetic torque between conditions	CWI5, CWI10, CWI20 & CON = time to exhaustion and total work performed CON > CWI5, CWI10 & CWI20 ↑ T_{re} 75 & 80-mins post exercise CWI5, CWI10 & CWI20 > CON ↓ T_{re} 45-80mins post time to exhaustion test CWI5, CWI10 & CWI20 > CON ↓ muscle temperature 45-mins post time to exhaustion test CWI10 & CWI20 > CWI5 ↓ muscle temperature immediately post-recovery CWI5, CWI10, CWI20 & CON = isometric and isokinetic torque

Halson et al, 2008[42]	Male endurance trained cyclists (age = 23.8 ± 1.6 years; VO_{2max} = 71.3 ± 1.2 mL·Kg^{-1}·min^{-1}) N = 11	Pre: ~40-min TT in heat (34.3 ± 1.1°C, 41.2 ± 3.0% rh) – first 20-mins fixed workload, final 20-mins same amount of work (kJ) as first 20-min but completed as quickly as possible	CWI (11.5°C, mesosternal height) Passive recovery (CON) [24.2 ± 1.8°C, 45.6 ± 6.5% rh] Duration: 20-mins passive rest followed by 3 x 60s per conditions with 2-mins seated rest between [24.2 ± 1.8°C, 45.6 ± 6.5% rh]	HR T_{re} BLa T_{sk} Mean body temperature Cooling rate pH, chloride, glucose, bicarbonate, potassium, sodium, PCO_2, PO_2, plasma CK, IGF-1, testosterone, GH, plasma CRP, IL-6, cortisol concentration, plasma prolactin concentration, plasma adrenaline, plasma noradrenaline Ratings of perceived: Physical, mental, muscular recovery and general fatigue	CWI ↓ HR over time (post-exercise to 40mins post-exercise) (CWI: Δ116 ± 9 b·min^{-1}, CON: Δ106 ± 4 b·min^{-1}, $p = 0.02$) mean body temperature over time (CWI: -6.3 %, CON: -3.8 %, $p < 0.05$) T_{sk} over time (CWI: -20.2 %, CON: -3.7 %, $p < 0.05$) and PO_2 40-mins post-exercise (CWI: 59.46 ± 10.40 mmHg, CON: 67.71 ± 9.07 mmHg, $p = 0.015$) vs CON CWI ↓ T_{re} vs CON 40-mins post-exercise (CWI: Δ1.99 ± 0.50 °C, CON: Δ1.49 ± 0.50 °C, $p = 0.01$) CWI ↑ cooling rate (CWI: 0.009 ± 0.03 °C·min^{-1}, CON: 0.001 ± 0.001 °C·min^{-1}, $p < 0.05$), ratings of perceived physical recovery (CWI: 6.8 ± 1.5, CON: 6.4 ± 1.7) and mental recovery vs CON (CWI: 6.7 ± 1.8, CON: 6.1 ± 1.7) No sig dif between conditions for PH, chloride, glucose, bicarbonate, potassium, sodium, PCO_2, CK, IGF-1, testosterone, GH, plasma CRP, IL-6, cortisol concentration, plasma prolactin concentration, plasma adrenaline and plasma noradrenaline or BLa CWI ↓ perceived muscle soreness (CWI: 3.8 ± 2.6, CON: 5.0 ± 2.9) and general fatigue (CWI: 5.3 ± 2.0, CON: 6.3 ± 2.0) vs CON	CWI > CON ↓ HR, T_{re}, T_{sk} and mean body temperature CWI & CON = BLa, PH, chloride, glucose, bicarbonate, potassium, sodium, PCO_2, CK, IGF-1, testosterone, GH, plasma CRP, IL-6, cortisol concentration, plasma prolactin concentration, plasma adrenaline and plasma noradrenaline CWI > CON ↑ cooling rate CWI > CON ↓ PO_2 40-mins post-exercise CWI > CON ↑ perceived physical recovery and mental recovery CWI > CON ↓ perceived muscle soreness and general fatigue

Stanley et al, 2012[38]	Endurance trained male cyclists (age = 27 ± 7 years; VO_{2max} = 63.9 ± 7.2 mL·Kg^{-1}·min^{-1}; PPO = 418 ± 40 W) N = 18	Pre: 8 x 4-mins cycling @ 80% PPO with 1-min AR (50% PPO) between intervals Post: Performance trial (standardized amount of work = 75% PPO x 15-mins)	CWI (14 ± 1°C, shoulder height) CWT (1-min CWI [14 ± 1°C], 3 x 2-mins HWI [40 ± 1°C] and ending with 1-min CWI) Passive rest (CON) [22°C, rh not described] Duration: 20-mins post-exercise each conditions implemented: CWI = 5-mins + 5-mins passive seated CWT = 10-mins CON = 10-mins An additional 160-mins passive seated for all conditions	Time to completion HR HR_{max} Power output ΔrMSSD (baseline vs during passive recovery) Perceived: General fatigue, mental recovery, leg soreness, physical recovery	No sig dif between conditions for HR and HR_{max} (during performance trial), time to completion, power output and perceived mental recovery CWI ↓ HR during first 10% of performance trial vs CON & CWT (*likely lower*) CWI ↓ power output during first 10% of performance trial vs CON (*likely lower*) CWT ↑ power output between 40 – 80 % the duration of the performance trial vs CON (*very likely higher*) CWI & CWT ↑ ΔrMSSD vs CON (*large* effect size) CWI ↑ ΔrMSSD vs CWT (*small* effect size) CWI ↓ perceived general fatigue vs CON (*very likely lower*) CWT ↓ perceived general fatigue vs CON (*likely lower*) CWI & CWT ↓ perceived leg soreness vs CON (*almost certainly lower*) CWI ↑ perceived physical recovery vs CON (*possibly higher*) CWT ↑ perceived physical recovery vs CON (*likely higher*)	CWI, CWT & CON = HR, HR_{max}, time to completion, power output and perceived mental recovery CON > CWI maintaining HR and power output during first 10% of performance trial duration CWT > CON ↑ power output between 40-80% duration of performance trial CWI & CWT > CON ↑ ΔrMSSD and ↓ perceived leg soreness CWI > CWT ↑ ΔrMSSD ↓ and perceived general fatigue CWI > CON ↓ perceived general fatigue and ↑ perceived physical recovery CWT > CWI ↑ perceived physical recovery

Stanley et al, 2013[9]	Endurance trained male cyclists (age = 27 ± 6 years; VO_{2max} = 64.8 ± 6.0 mL·Kg^{-1}·min^{-1}; PPO = 415 ± 39 W) N = 11	Pre: 2 x 3 day (days 1-6) training block separated by 11-days between each 3-day block. 120-min cycling per day (66 ramped sprints beginning at 5s and working up to 15s per sprint and 2 x 2-min TT's and 1 x 5-min TT)	CWI (shoulder height, 10 ± 1°C) Passive (CON) [27°C, rh not described] Duration: 15-mins passive seated followed by 5-mins per condition 5-mins to return to lab and complete subsequent exercise protocol	Sprint mean power Sprint cadence TT mean power TT cadence Mean HR HR_{max} $HR_{post-session}$ $HR_{post-recovery}$ HRV: $rMSSD_{post-recovery}$ RPE Perceived: Tiredness Mental -recovery Leg soreness	CWI attenuated ↓ sprint power day's 1-3 vs CON (within-trial change mean ± 90%CL, CWI: +2.4 ±2.3 %, CON: -9.6 ±5.0 %) CWI attenuated ↓ sprint cadence day's 1-3 vs CON (CWI: -2.1 ±1.5 %, CON: -4.1 ±1.8 %) TT mean power *unclear* between conditions CWI ↓ TT cadence days 1-3 vs CON (CWI: -0.4 ±1.3 %, CON: +0.4 ±2.1 %) CWI ↑ mean HR during exercise days 1-3 vs CON (CWI: -2.3 ±1.3 %, CON: -3.9 ±1.4 %) HR_{max} , $HR_{post-session}$ no sig dif between conditions CWI ↓ $HR_{post-recovery}$ day 1 vs CON (*certainly lower*) CWI ↑ $rMSSD_{post-recovery}$ day 1 vs CON (*certainly higher*) RPE, tiredness & mental recovery *unclear* between conditions CWI ↓ perceived leg soreness day 2 vs CON (*likely lower*)	CWI > CON attenuating ↓ sprint power and cadence CON > CWI maintaining TT cadence CWI > CON ↑ mean HR during exercise CWI & CON = HR_{max}, $HR_{post-session}$, RPE, perceived tiredness and perceived mental recovery CWI > CON ↓ $HR_{post-recovery}$ day 1 CWI > CON ↑ $rMSSD_{post-recovery}$ day 1 CWI > CON ↓ leg soreness day 2

Vaile et al, 2008[31]	Well-trained male cyclists (age = 32 ± 5 years; VO_{2max} = 70.7 ± 7.9 $mL \cdot Kg^{-1} \cdot min^{-1}$) N = 10	Pre (Ex1): 30-min cycling in heat (34 ± 0.2°C, 39.4 ± 1.5 % rh, 15-min @ 70% PPO and a 15-min maximal cycling TT) Post (Ex2): 30-min cycling in heat (34 ± 0.2°C, 39.4 ± 1.5 % rh, 15-min @ 70% PPO and a 15-min maximal cycling TT)	Shoulder height for all CWI conditions Intermittent CWI, 10°C (ICWI10) Intermittent CWI, 15°C (ICWI15) Intermittent CWI, 20°C (ICWI20) Continuous CWI, 20°C, in bath for entire 15-mins (CCWI20) AR (15-mins @ 40% VO_{2max}, 31.1 ± 2.6°C) Duration: Intermittent CWI = 5 x 1-min in bath, 2-mins out of bath (29.2 ± 1.4°C, 58 ± 2.1 % rh) 15-mins total per condition 40-mins passive recovery (34 ± 0.2°C, 39.4 ± 1.5 % rh)	30-min cycling total work (kJ) Body temperature BLa RPE $HR_{post\text{-}intervention}$ $HR_{post\text{-}recovery}$	All CWI conditions maintained total work vs AR ($p < 0.05$). ICWI 15°C ↑ total work Ex1 vs Ex2 but no sig dif (Ex1: 498 ± 47 kJ, Ex2: 500 ± 46 kJ, $p > 0.05$) No sig dif between CWI conditions for total work ($p > 0.05$) All CWI conditions ↓ post-recovery body temperature vs AR (CWI10: 34.6 ± 0.6 ° C, CWI15: 35.3 ± 0.6 °C, CWI20: 36.5 ± 0.5 °C, CCWI20: 36.1 ± 0.2 °C, AR: 38.2 ± 0.4 °C, $p < 0.05$) AR ↓ BLa post-recovery vs all CWI conditions ($p < 0.05$) ICWI10, ICWI15 & CCWI20 ↓ RPE mid-way through both exercise tasks vs AR ($p < 0.05$) CWI no sig dif post-exercise RPE vs AR ($p > 0.05$) AR ↑ $HR_{post\text{-}intervention}$ vs all CWI conditions (ICWI10: 86 ± 12 $b \cdot min^{-1}$, ICWI15: 80 ± 7 $b \cdot min^{-1}$, CWI20: 81 ± 12 $b \cdot min^{-1}$, CCWI20: 81 ± 9 $b \cdot min^{-1}$, AR: 128 ± 7 $b \cdot min^{-1}$, $p < 0.001$) AR ↑ $HR_{post\text{-}recovery}$ vs ICWI10, ICWI15 & CCWI20 (ICWI10: 74 ± 13 $b \cdot min^{-1}$, ICWI15: 69 ± 8 $b \cdot min^{-1}$, CCWI20: 71 ± 8 $b \cdot min^{-1}$, AR: 87 ± 11 $b \cdot min^{-1}$,) but not ICWI20 (ICWI20: 80 ± 6 $b \cdot min^{-1}$)	All CWI conditions > AR maintaining total work and ↓ post-recovery body temperature AR > all CWI conditions ↓ BLa ICWI10, ICWI15, CCWI20 > AR ↓ RPE during exercise All CWI conditions & AR = RPE post-exercise AR > all CWI conditions ↑ $HR_{post\text{-}intervention}$ AR > ICWI10, ICWI15 & CCWI20 ↑ $HR_{post\text{-}recovery}$

Vaile et al, 2008[34]	Endurance trained male cyclists (age = 32.2 ± 4.3 years; VO_{2max} = 68.8 ± 3.6 mL·Kg^{-1}·min^{-1}) N = 12	Pre: 5 consecutive days - 66 max sprints (5-15s with a specific work to rest ratio of 1:6, 1:3 or 1:1 – rest is AR @ 40-50% PPO) + 9-min TT (2 x 2-min & 1 x 5-min)	CWI (15°C, shoulder height) HWI (38°C, shoulder height) CWT (7 x 15°C 1-min; 38°C 1-min, shoulder height) Passive seated (CON) [room temperature and humidity not stipulated] Duration: 14-mins	**Sprints:** Mean power **TT:** TT total work performed (kJ) Mean power T_{re} HR RPE	**Sprints:** CWT & CWI maintained/↑ mean power output days 4-5 ($p < 0.01$) and ↑ mean power over 5 days (CWI: +0.1 to +1.4 %, CWT: +0.5 to +2.2 %) vs CON CON & HWI ↓ mean power over 5 days (CON: -1.7 to -4.9 %, HWI: -0.6 to -3.7 %) **TT's:** CWI & CWT ↑ total work vs HWI & CON days 4 & 5 ($p < 0.05$). Day 5 total work CWI = 160 ± 20 kJ, CWT = 161 ± 20 kJ, HWI = 156 ± 22 kJ & CON = 155 ± 22 kJ CON ↓ mean power by 2.6 – 3.8 % over 5 days CWI & CWT ↑ mean power over 5 days (CWI: +0.1 to +1.0 %, CWT: 0.0 to +1.7 %, $p < 0.05$) HWI mean power ranged from an ↑ of 1.5% to a ↓ of 3.4% over the 5 days No sig dif T_{re} post-recovery (CWI: 37.3 ± 0.2, HWI: 37.6 ± 0.2, CWT: 37.5 ± 0.2, CON: 37.4 ± 0.2) and RPE between conditions While no sig dif ($p > 0.05$) HWI ↓ post-exercise HR vs CON on days 2 – 5 (ES: >0.6, *medium* effect) While no sig dif ($p > 0.05$) CWT & CWI ↑ post-exercise HR vs CON on days 4 – 5 (CWT: ES: 0.6, CWI: ES:1.2)	CWT & CWI > CON maintaining/↑ sprint mean power output days 4-5 CWT & CWI > HWI & CON ↑ TT total work performed CWT & CWI > HWI & CON ↑ TT mean power output over 5 days CWT, CWI, HWI & CON = T_{re} post-recovery HWI > CWT, CWI & CON ↓ HR post-exercise days 2-5 CWT, CWI, HWI & CON = RPE

Vaile et al, 2011[32]	Endurance trained male cyclists (age = 33.7 ± 4.7 years; VO_{2max} = 66.7 ± 6.1 $mL \cdot Kg^{-1} \cdot min^{-1}$ N = 10	Pre & post: 35-mins cycling in heat [32.8 ± 1.1 °C, 43.6 ± 1.8 % rh] (15-mins @ 70% PPO; 15-min TT)	CWI (15°C, shoulder height) AR @ 40% PPO (32.8 ± 1.1°C) Duration: 15-mins per conditions Passive rest in a supine position for 40-mins (32.8 ± 1.1°C, 43.6 ± 1.8 % rh)	15-min TT total work performed (kJ) T_{re} Limb blood flow (arm blood flow, leg blood flow & leg to arm blood flow ratio) HR BLa	AR↓ total work performed (pre to post Δ: -1.8 ± -1.1 %) CWI ↑ total work performed (pre to post Δ: +0.10 ± 0.7 %) CWI ↓ T_{re} post-recovery and post-exercise ($p < 0.05$) CWI ↓ leg and arm blood flow vs AR during recovery and post-recovery CWI ↓ arm blood flow post-exercise vs AR ($p < 0.05$) CWI ↑ leg to arm blood flow ratio vs AR during recovery No sig dif post-exercise blood flow ratio between conditions CWI ↓ HR during and post recovery vs AR (CWI: 78 ± 15 $b \cdot min^{-1}$, AR: 90 ± 11 $b \cdot min^{-1}$, $p < 0.05$) CWI ↓ HR during first 5-mins of exercise vs AR AR ↓ BLa post-recovery vs CWI (CWI: 4.5 ± 1.2 mM, AR: 2.3 ± 0.8 mM, $p < 0.05$)	CWI > AR ↑ total work performed CWI > AR ↓ T_{re} , leg and arm blood flow during recovery CWI > AR ↑ leg to arm blood flow ratio during recovery CWI & AR = leg to blood flow ratio post-exercise CWI > AR ↓ HR AR > CWI ↓ BLa

Buchheit et al, 2008[36]	Male cyclists (age = 29 ± 6 years; VO_{2max} = 56.5 ± 5.0 mL·Kg^{-1}·min^{-1}) N = 10	Pre & Post: 1-km maximal cycling TT in heat (35°C, 40% rh)	CWI (14°C, mid sternal level) duration: 5-mins + 15-mins passive seated Passive seated (CON) [35 ± 0.3 °C, 40 ± 3% rh] duration: 20-mins	Perceived recovery Mean power Time to completion T_{re} $LnHF_{post\text{-}recovery\ and\ post\text{-}exercise}$ $rMSSD_{post\text{-}exercise}$	CWI ↑ perceived recovery vs CON (CWI: 6.5 ± 2.1, CON: 4.5 ± 2.0, $p < 0.01$) Mean power no sig dif between conditions ($p = 0.90$) No sig dif time to completion between conditions No sig dif T_{re} between conditions post-recovery CWI ↑ $LnHF_{post\text{-}recovery\ and\ post\text{-}exercise}$ vs CON (post-recovery; $p = 0.05$, ES = 1.0, *large*, post-exercise; $p = 0.11$, ES = 1.2, *large*) CWI ↑ $rMSSD_{post\text{-}exercise}$ vs CON (CWI: 9.9 ± 4.9 ms, CON: 6.6 ± 1.3 ms, ES > 0.80, *large*)	CWI > CON ↑ perceived recovery CWI & CON = mean power, time to completion, T_{re} CWI > CON ↑ $LnHF_{post\text{-}recovery\ and\ post\text{-}exercise}$ CWI > CON ↑ $rMSSD_{post\text{-}exercise}$
Christensen & Bangsbo, 2016 (Part B)[37]	Highly trained male road cyclists (age = 29 ± 6 years, VO_{2max} = 67 ± 5 mL·Kg^{-1}·min^{-1}; mean power = 360-460 W) N = 12	Pre & Post: ~4-min cycling TT (fixed load [40 ± 4 N], power output determined solely by cadence	CWI (15°C to umbilicus level) CON (temperature and body action not described) Duration: 15-mins per condition 2h 35m before next performance test (nature of participants recovery not described i.e. passive seated)	4-min TT mean power BLa Perceived readiness	4-min TT mean power no sig dif between conditions (CWI: 406 ± 43 W, CON: 405 ± 38 W, $p = 0.66$) CWI ↑ 30s mean power during 4-min TT vs CON (CWI: 435 ± 64 W, CON: 425 ± 63 W, $p < 0.05$) and also from 31-60s ($p < 0.01$) BLa no sig dif between conditions ($p = 0.11$) Perceived readiness no change between conditions (CWI & CON: 7 ± 1)	CWI & CON = 4-min TT mean power, BLa & readiness CWI possible placebo lead to ↑ pacing profile as observed by an ↑ 30s mean power during 4-min TT

Chan et al, 2016[39]	Junior elite male cyclists (age = 16 ± 1 year; VO_{2max} = 64.7 ± 4.3 mL·Kg^{-1}·min^{-1} N = 8	Pre: 15-mins cycling @ 75% PPO & 15-min TT in heat (TT1, 31°C, 74% rh) Post: 15-mins cycling @ 75% PPO & 15-min TT in heat (TT2, 31°C, 74% rh)	CWI (15°C, mid-sternum level) CCT (15 °C, ankle and thigh of both legs, rhythmic compression setting HIGH) AR @ 40 % PPO (31°C) Duration: 10-mins passive seated in heat (31°C, 74% rh), 15-mins per condition, 30-mins passive seated in heat	Mean power Core body temperature BLa RPE $HR_{recovery}$	No sig dif TT2 mean power between conditions (p = 0.551) CWI ↓ core body temperature 15-mins during recovery vs CCT (p = 0.011) CWI ↓ core body temperature vs AR post-recovery (p = 0.033) AR ↓ BLa vs CCT & CWI (AR: -75%, CCT: -62%, CWI: -62%) No sig dif RPE between conditions No sig dif $HR_{recovery}$ between conditions (p = 0.178)	CCT, CWI & AR = mean power, RPE & $HR_{recovery}$ CWI > CCT ↓ core body temperature post treatment CWI > AR ↓ core body temperature post-recovery AR > CWI & CCT ↓ BLa
Schniepp et al, 2002[40]	Well-trained cyclists (age = 29.7 ± 6.3 years) N = 10	Pre(s1): 30s sprint Post(s2): 30s sprint	CWI (12°C, hip height) Passive seated (CON) Duration: 15-mins	PPO Mean power Mean $HR_{post-recovery}$	CWI ↓ PPO vs CON (CON: -52.2 W [-4.7 %], CWI: -157.6 W [-13.7 %], $p < 0.001$) CWI ↓ mean power vs CON (CON: - 18.4 W [-2.3 %], CWI: -76.9 W [-9.5 %], $p < 0.001$) CWI ↓ mean $HR_{post-recovery}$ vs CON (CON: +2.4 b·min^{-1} [+1.5 %], CWI: -6.8 b·min^{-1} [-4.2 %], $p < 0.02$)	CON > CWI attenuating ↓ PPO and mean power CWI ↓ mean $HR_{post-recovery}$

VO_{2max} maximal oxygen uptake, *N* number of cyclists, VO_2 oxygen uptake, *rh* relative humidity, T_{sk} skin temperature, T_{mus} muscle temperature, T_{re} rectal temperature, *MVIC* maximum voluntary isometric contraction, *SMVIC* maximum voluntary isometric contraction with superimposed electrical stimulation, *TT* time trial, *W* Watts/power output, *PPO* peak power output, *RPE* ratings of perceived exertion, *CWI* cold water immersion, *CWT* contrast water therapy, *HWI* hot water immersion, *CCT* cold compression therapy, *RPM* revolutions per minute, *HR* heart rate, *BLa* blood lactate concentration, *CON* control condition/passive recovery, HR_{max} maximum heart rate, *pH* potential of hydrogen, PCO_2 partial pressure of carbon dioxide, PO_2 partial pressure of oxygen, *CK* creatine kinase, *IGF-1* insulin-like growth factor 1, *GH* growth hormone, *CRP* C-reactive protein, *IL-6* interleukin 6, *AR* active recovery, *rMSSD* natural logarithm of the square root of mean squared differences of successive R-R intervals, *HRV* heart rate variability, *LnHF* natural logarithm of high frequency power density.

Contrast, Thermoneutral and Hot Water Immersion/Therapy

Contrast water therapy (CWT) can be described as brief exposure to contrasted temperature, typically ranging from 15°C and below for the lower range and 35°C and above for the upper temperature range (table 5).[6] It is proposed that CWT improves muscle soreness, inflammation and performance recovery.[34]

Thermoneutral water immersion (TWI) can be described as exposure to temperate-water, typically around 26°C and has been suggested effective in the removal of heat when exercise hyperthermia is of concern. Therefore, in order to maintain exercise performance in hot and humid conditions, TWI may be as effective as CWI.[43] Indeed, it has been suggested that a reduction in muscle temperature can impair cross-bridge cycling, motor unit activation and enzyme activity rate;[40] therefore warranting further investigation for the use of TWI.

Hot water immersion/therapy (HWI) involves immersing the body into water temperatures typically exceeding 36°C.[34] Whether or not HWI is beneficial to exercise recovery and performance, or the physiological mechanisms by which HWI would impact these variables are unknown.[34]

CWT has been shown more beneficial than passive rest alone and appears dose-dependent with 6-mins [1-min hot water (38.4 ± 0.6°C): 1-min cold (14.6 ± 0.3°C)] shown to improve 15-min TT total work performed, where 12-mins and 18-mins had no significant difference on 15-min TT total work performed.[4] There also appears to be an interaction with dose and intensity, with both 6 and 12-mins shown to improve 5 x 15s sprint cycling performance in the same study. However, 18-mins appears too long and ineffective at improving both sprint and TT total work performed.[4] Furthermore, when used for 12-mins, CWT was most effective when compared with 6-mins, 18-mins and a control condition for improving PPO

(CWT6: 748 ± 19 W, CWT12: 772 ± 14 W, CWT18: 753 ± 13 W, CON: 754 ± 21 W)[4] and when the ratio of hot immersion increased to 1:2-mins (cold:hot); 12-mins of CWI improved 5-min TT mean power by 4.1 %.[6] In support, 14-mins of CWT (7 x 15°C 1-min; 38°C 1-min, shoulder height) improved 9-min TT mean power by up to 1.7% over 5-days and sprint cycling mean power by up to 2.2% over the same 5-day protocol.[34] Additionally, the improvement in TT mean power from CWT was more beneficial than HWI, with mean power in the HWI condition ranging from an increase of 1.5% to a reduction of 3.4% over the 5 days. When examining total work performed, CWT again, was more beneficial than HWT (CWT = 161 ± 20 kJ, HWI = 156 ± 22 kJ & CON = 155 ± 22 kJ).[34]

One study exhibited no improvements in time to completion or power output from the use of CWT when compared with a control.[38] However, the performance trial in this study was based on a standardized amount of work (75% PPO x 15-mins) and interestingly, authors reported an increase in power output during 40-80% of the performance trial from the use of CWT. Furthermore and as described above, the same study that reported no benefit from the use of CWT used an extensive recovery duration (190-mins) which would have diluted the impact of the recovery intervention.

CWT used between 6-14mins with a temperature of 38°C for hot water immersion and 15°C for the cold water immersion component and a ratio of 1:1-mins or 1:2-mins for cold:hot has been shown to improve both TT total work performed, TT and sprint mean power output and sprint PPO. Performance benefits can be observed from as short as a 15s sprint, up to a 15-min TT.

HWI appears detrimental to performance and as alluded to previously, a rise of core temperature beyond 39°C can result in increased perceived fatigue, a reduction in exercise performance and premature exercise termination.[30, 31] Therefore, a recovery strategy that aims to expose athletes to HWI alone seems counterintuitive. These performance benefits were associated with a reduction in BLa of 2.7 mmol·L^{-1},[6] a decrease in perceived muscle soreness and whole body fatigue[4, 6] and a reduction in core-temperature post-recovery when CWT was used for 12 & 18-mins.[4] A placebo effect may be responsible in part for the resultant performance benefits as the least effective duration (18-mins) was associated with an increase in perceived effort, while one of the most effective durations (12-mins) was reported as the perceived preferred duration in the one study that examined a dose-response relationship.[4] However and in contrast, subjects reported a reduction in perceived motivation when CWT was used for 12-mins.[4]

TWI has been shown greater than passive rest alone at reducing 20-km TT time to completion (TWI: 44 ± 2.7 mins, CON: 46.7 ± 5.4 mins, $p < 00.05$) and improving average speed (TWI: 27.4 ± 2.1 km/h, CON: 25.9 ± 2.4 km/h, $p < 0.05$).[43] This improvement in performance was associated with a reduction in T_{re} and increased HR recovery (TWI: 62 ± 10 b·min^{-1}, CON: 90 ± 8 b·min^{-1}, $p < 0.001$). The use of TWI seems promising and future research should use four conditions and compare TWI, CWI, CWT and a CON condition to determine the most effective form of water immersion.

Table 5. Summary of Studies Examining the Use of Contrast, Thermoneutral and Hot Water Immersion/Therapy Post-exercise in Cyclists.

Study	**Sample/ Training Status/ Sample Size**	**Exercise Protocol**	**Recovery Strategy & Duration**	**Markers of Recovery/ Performance**	**Results**	**Overall**
Lit et al, 2014[43]	Trained male cyclists representing Kelantan state (age = 19 ± 5 years; VO_{2max} = 58 ± 4 $mL \cdot Kg^{-1} \cdot min^{-1}$) N = 9	Pre: 60-mins cycling in heat @ 70% VO_{2max} (31.2 ± 0.3 °C, 72 ± 0.7 % rh) Post: 20-km TT	TWI (25°C) Passive rest (CON) [25°C, rh not described, shoulder height] Duration: 30-mins	Time to completion (min) Average speed (km/h) Post-exercise & post-recovery HR T_{re} Serum F2-isoprostanes GSH:GSSG ratio	TWI ↓ time to completion vs CON (TWI: 44 ± 2.7 mins, CON: 46.7 ± 5.4 mins, $p < 00.05$) TWI ↑ average speed vs CON (TWI: 27.4 ± 2.1 km/h, CON: 25.9 ± 2.4 km/h, $p < 0.05$) TWI ↓ post-exercise HR (TWI: 166 ± 10 $b \cdot min^{-1}$, CON: 168 ± 5 $b \cdot min^{-1}$) and post-recovery HR (TWI: 62 ± 10 $b \cdot min^{-1}$, CON: 90 ± 8 $b \cdot min^{-1}$, $p < 0.001$) vs CON TWI ↓ T_{re} 15-mins during recovery ($p < 0.05$) and post-recovery (post recovery Δ 0.9 °C, $p < 0.01$) TWI ↓ T_{re} vs CON during entire 20-km TT ($p < 0.05$) TWI ↓ T_{re} post-exercise vs CON (TWI: 37.8 ± 0.4 °C, CON: 38.5 ± 0.7 °C, $p < 0.01$) No sig dif Serum F2-isoprostanes and GSH:GSSG ratio between conditions ($p > 0.05$)	TWI > CON ↓ time to completion TWI > CON ↑ average speed TWI > CON ↓ HR TWI > CON ↓ T_{re}

Menetrier et al, 2013[6]	Competitive male cyclists (PPO = 5.0 ± 0.2 W/Kg) N = 12	Pre: 10-min cycling (5-mins 80% PPO & 5-mins 90% PPO) Post: 5-min maximal cycling	Passive seated [~21 °C, ~30% rh] (CON) CWT (4 x 3-min to top thigh; 1-min cold bath [10-12°C], 2-min hot bath [36-38°C], 5s changeover) CS (according to manufacturer: calf = 27mmHg; thigh = 14mmHg) Duration: 1.5-mins passive seated pre and post condition 12-mins per condition	5-min maximal cycling mean power BLa Perceived muscle soreness HR RPE	CWT ↑ mean power vs CON (368 ± 12 W, +4.1 ± 0.7 %; $p < 0.001$) and vs CS (+2.2 ± 0.8 %; $p < 0.05$) CS ↑ mean power vs CON (361 ± 15 W, +1.8 ± 1.0 %; $p < 0.05$) CWT & CS ↓ BLa vs CON (CWT: 5.7 ± 1.0 mmol·L^{-1}; $p < 0.001$, CS: 7.3 ± 1.2 mmol·L^{-1}; $p < 0.05$, CON: 8.4 ± 1.0 mmol·L^{-1}) CWT ↓ BLa vs CS ($p < 0.05$) CWT & CS ↓ perceived muscle soreness vs CON (CWT: 1.1 ± 0.5 au; $p < 0.001$, CS: 1.6 ± 0.4 au; $p < 0.001$, CON: 3.2 ± 0.5 au) HR during exercise & RPE no sig dif between conditions ($p > 0.05$)	CWT & CS > CON ↑ mean power & ↓ perceived muscle soreness and BLa CWT > CS ↑ mean power & ↓ BLa CWT, CS & CON = HR during exercise and RPE

Versey et al, 2011[4]	Trained male cyclists (age = 32.1 ± 7.6 years; VO_{2max} = 64.5 ± 5.4 mL·Kg^{-1}·min^{-1}) N = 11	Pre (bout 1): 6 x [5 x 15s sprint cycling & 3 x 5-min TT] Post (bout 2): 6 x [5 x 15s sprint cycling & 3 x 5-min TT]	CWT 6-mins, shoulder height (CWT6) CWT 12-mins, shoulder height (CWT12) CWT 18-mins, shoulder height (CWT18) Passive (CON) [2-hrs, 24.2 ± 1.2°C. 48.1 ± 13.1 % rh] Duration: 10-mins post exercise: 1-min hot water (38.4 ± 0.6°C) 5s changeover 1-min cold (14.6 ± 0.3°C) All trails seated at rest for the remainder of the duration of CON trial (23.9 ± 2.0°C)	Total work performed during TT & sprints (kJ) Sprints PPO Core temperature HR_{mean}, TT HR_{max}, sprints RPE Perceived: Effort, motivation, whole body fatigue, muscle soreness Perceived preferred duration	CWT6 ↑ TT total work performed vs CON (CWT6: 281 ± 17 kJ, CON: 277 ± 18 kJ) No sig dif CWT12 & 18 TT total work performed vs CON CWT6 & CWT12 ↑ sprints total work performed vs CON (CWT6: 263 ± 18 kJ, CWT12: 266 ± 15 kJ, CON: 255 ± 20 kJ) No sig dif CWT18 sprints total work performed vs CON CWT12 ↑ sprints PPO (CWT6: 748 ± 19 W, CWT12: 772 ± 14 W, CWT18: 753 ± 13 W, CON: 754 ± 21 W) and perceived preferred duration vs all other conditions CWT12 & CWT18 ↓ core temperature post-recovery vs CON (ES; CWT12 = 0.69, CWT18 = 0.77) CWT12 ↑ core temperature post-exercise bout 2 vs CWT6 (ES = 0.61) No sig dif HR_{mean} TT, HR_{max} sprints or RPE CWT18 ↑ 5-min TT bout 2 perceived effort vs CON (ES:1.2 ±1.0, *very large*) CWT12 ↓ perceived motivation vs CON (ES: -0.28 ±0.17, *small*) CWT6 & CWT18 ↓ perceived whole body fatigue post-recovery vs CON (CWT6: *small* effect, CWT18: *large* effect) CWT12 & CWT18 ↓ perceived muscle soreness vs CON ($p < 0.05$)	CWT6 > CON ↑ TT total work performed CWT12, CWT18 & CON = TT total work performed CWT6 & CWT12 > CON ↑ sprints total work performed CWT18 & CON = sprints total work performed CWT12 > all other conditions ↑ sprints PPO and perceived preferred condition CWT12 & CWT18 > CON ↓ core temperature and perceived muscle soreness CWT12 > CWT6 ↑ core temperature post-exercise All CWT conditions & CON = HR_{mean} TT, HR_{max} sprints and RPE CWT18 > CON ↑ 5-min TT perceived effort CWT12 > CON ↓ perceived motivation CWT6 & CWT18 > CON ↓ whole body fatigue post-recovery

Vaile et al, 2008[34]	Endurance trained male cyclists (age = 32.2 ± 4.3 years; VO_{2max} = 68.8 ± 3.6 mL·Kg^{-1}·min^{-1}) N = 12	Pre: 5 consecutive days - 66 max sprints (5-15s with a specific work to rest ratio of 1:6, 1:3 or 1:1 – rest is AR @ 40-50% PPO) + 9-min TT (2 x 2-min & 1 x 5-min)	CWI (15°C, shoulder height) HWI (38°C, shoulder height) CWT (7 x 15°C 1-min; 38°C 1-min, shoulder height) Passive seated (CON) [room temperature and humidity not stipulated] Duration: 14-mins	**Sprints:** Mean power **TT:** TT total work performed (kJ) Mean power T_{re} HR RPE	**Sprints:** CWT & CWI maintained/↑ mean power output vs CON days 4-5 ($p < 0.01$) CON & HWI ↓ mean power over 5 days (CON: -1.7 to -4.9 %, HWI: -0.6 to -3.7 %) CWT & CWI ↑ mean power over 5 days (CWI: +0.1 to +1.4 %, CWT: +0.5 to +2.2 %) **TT's:** CWI & CWT ↑ total work vs HWI & CON days 4 & 5 ($p < 0.05$). Day 5 total work CWI = 160 ± 20 kJ, CWT = 161 ± 20 kJ, HWI = 156 ± 22 kJ & CON = 155 ± 22 kJ CON ↓ mean power by 2.6 – 3.8 % over 5 days CWI & CWT ↑ mean power over 5 days (CWI: +0.1 to +1.0 %, CWT: 0.0 to +1.7 %, $p < 0.05$) HWI mean power ranged from an ↑ of 1.5% to a ↓ of 3.4% over the 5 days No sig dif T_{re} post-recovery (CWI: 37.3 ± 0.2, HWI: 37.6 ± 0.2, CWT: 37.5 ± 0.2, CON: 37.4 ± 0.2) and RPE between conditions While not statistically significant ($p > 0.05$) HWI ↓ post-exercise HR vs CON on days 2 – 5 (ES: >0.6, *medium* effect) While not statistically significant ($p > 0.05$) CWT ↑ post-exercise HR vs CON on days 4 – 5 (ES: 0.6, *medium* effect) While not statistically significant ($p > 0.05$) CWI ↑ post-exercise HR vs CON on day 4 (ES: 1.2, *large* effect)	CWT & CWI > CON maintaining/↑ sprint mean power output days 4-5 CWT & CWI > HWI & CON ↑ TT total work performed CWT & CWI > HWI & CON ↑ TT mean power output over 5 days CWT, CWI, HWI & CON = T_{re} post-recovery HWI > CWT, CWI & CON ↓ HR post-exercise days 2-5 CWT, CWI, HWI & CON = RPE

Stanley et al, 2012[38]	Endurance trained male cyclists (age = 27 ± 7 years; VO_{2max} = 63.9 ± 7.2 mL·Kg^{-1}·min^{-1}; PPO = 418 ± 40 W) N = 18	Pre: 8 x 4-mins cycling @ 80% PPO with 1-min AR (50% PPO) between intervals Post: Performance trial (standardized amount of work = 75% PPO x 15-mins)	CWI (14 ± 1°C, shoulder height) CWT (1-min CWI [14 ± 1°C], 3 x 2-mins HWI [40 ± 1°C] and ending with 1-min CWI) Passive rest (CON) [22°C, rh not described] Duration: 20-mins post-exercise each conditions implemented: CWI = 5-mins + 5-mins passive seated CWT = 10-mins CON = 10-mins An additional 160-mins passive seated for all conditions	Time to completion HR HR_{max} Power output ΔrMSSD (baseline vs during passive recovery) Perceived: General fatigue, mental recovery, leg soreness, physical recovery	No sig dif between conditions for HR and HR_{max} (during performance trial), time to completion, power output and perceived mental recovery CWI ↓ HR during first 10% of performance trial vs CON & CWT (*likely lower*) CWI ↓ power output during first 10% of performance trial vs CON (*likely lower*) CWT ↑ power output between 40 – 80 % the duration of the performance trial vs CON (*very likely higher*) CWI & CWT ↑ ΔrMSSD vs CON (*large* effect size) CWI ↑ ΔrMSSD vs CWT (*small* effect size) CWI ↓ perceived general fatigue vs CON (*very likely lower*) CWT ↓ perceived general fatigue vs CON (*likely lower*) CWI & CWT ↓ perceived leg soreness vs CON (*almost certainly lower*) CWI ↑ perceived physical recovery vs CON (*possibly higher*) CWT ↑ perceived physical recovery vs CON (*likely higher*)	CWI, CWT & CON = HR, HR_{max}, time to completion, power output and perceived mental recovery CON > CWI maintaining HR and power output during first 10% of performance trial duration CWT > CON ↑ power output between 40-80% duration of performance trial CWI & CWT > CON ↑ ΔrMSSD and ↓ perceived leg soreness CWI > CWT ↑ ΔrMSSD ↓ and perceived general fatigue CWI > CON ↓ perceived general fatigue and ↑ perceived physical recovery CWT > CWI ↑ perceived physical recovery

VO_{2max} maximal oxygen uptake, *N* number of cyclists, *rh* relative humidity, *TT* time trial, *TWI* thermoneutral water immersion/therapy, *CWT* contrast water therapy, *CWI* cold water immersion, *HWI* hot water immersion/therapy, *CON* control condition/passive rest, *HR* heart rate, T_{re} rectal temperature, *GSH* reduced glutathione, *GSSG* oxidised glutathione, *PPO* peak power output, *W/Kg* watts per kilogram of bodyweight, *CS* compression stockings, *BLa* blood lactate concentration, *RPE* ratings of perceived exertion, *W* watts, HR_{max} maximum heart rate, *AR* active recovery, *rMSSD* natural logarithm of the square root of mean squared differences of successive R-R intervals.

Electromyostimulation (EMS)

Only one study to our knowledge, has examined electromyostimulation/electronic muscle stimulation (EMS) on cyclists during a cycling exercise protocol (table 6).[8] EMS involves attaching electrodes to the skin and emitting electrical current to the muscle belly or muscle nerve in order to create small muscle contractions; it is believed that this stimulus increases blood flow, promotes the removal of metabolites, decreases muscle soreness and ultimately restores neuromuscular function and exercise performance.[44] In the study by Argus and colleagues,[8] participants were required to perform three bouts of 30s maximal sprint cycling, using a preload of 60s cycling at 4.5 W/Kg and 20-mins recovery between each bout. Whilst EMS was unable to significantly alter power results, a trend in BLa reduction was observed when compared with a passive control (4.9 ± 6.9 %, *possibly beneficial*) and EMS was also able to improve participants perceived recovery (0.7 ± 0.9, *likely beneficial*). As mentioned earlier, while a placebo effect may be responsible for the results observed, a belief questionnaire was used to attempt to control for a placebo effect. Only 2/8 participants accurately predicted the most effective recovery strategy therefore indicating that a placebo effect may not have been present. While further research is necessary to support the current findings, EMS appears to be an effective strategy for improving BLa clearance and perceptions of recovery. It should be noted that the EMS group performed the first sprinting bout at 15-20W greater than the opposing conditions and therefore while results were *unclear*, the potential for a performance improvement may occur in future research that aims to control pre-fatigue.

Table 6. Summary of Studies Examining the Use of Electromyostimulation Post-exercise in Cyclists.

Study	Sample/ Training Status/ Sample Size	Exercise Protocol	Recovery Strategy & Duration	Markers of Recovery/ Performance	Results	Overall
Argus et al, 2013[8]	Highly trained cyclists (A/B grade) N = 11	Pre: 30s max sprint cycling (S1) with 60s preload @ 4.5W/Kg Post 1 (S2) & Post 2 (S3): 30s max sprint cycling with 60s preload @ 4.5W/Kg	COMP (calf: 27 ± 6 mmHg; thigh: 18 ± 2 mmHg) EMS (15.7 ± 2.8 Hz) HUM Passive (CON) Duration: 2 x 20-mins between bouts (R1 & 2)	30s cycling mean power BLa TQR Belief	COMP attenuated ↓ mean power vs CON S1 – S2 (0.8 ± 1.2 %, *possibly beneficial*) & S1 – S3 (1.2 ± 1.9 %; *possibly beneficial*) HUM attenuated ↓ mean power vs CON from S1 – S3 (2.2 ± 2.5 %, *likely beneficial*) COMP no sig dif BLa or TQR vs CON ($p > 0.05$) HUM & EMS ↓ R2 BLa vs CON (HUM: 4.3 ± 7.9 %, *possibly beneficial,* EMS: 4.9 ± 6.9 %, *possibly beneficial*) EMS ↑ R2 TQR vs CON (0.7 ± 0.9, *likely beneficial*) 2 / 8 participants accurately predicted which strategy would enhance their recovery (belief).	COMP & HUM > CON attenuating ↓ mean power COMP & CON = BLa & TQR HUM & EMS > CON ↓ BLa EMS > CON ↑ TQR Possibly no placebo effect (2/8 belief)

N number of cyclists, *W/Kg* watts per kilogram of bodyweight, *COMP* compression garments/full length tights, *EMS* electromyostimulation/electronic muscle stimulation, *HUM* humidification therapy, *CON* control condition/passive rest, *R1 & 2* recovery one and recovery two, *BLa* blood lactate concentration, *TQR* perceived total quality recovery.

Humidification Therapy (HUM)

Only one study to our knowledge, has examined humidification therapy (HUM) on cyclists during a cycling exercise protocol (table 7).[8] HUM encompasses the delivery of high flow rates (5-50 $L \cdot min^{-1}$) of warm (37°C) humidified air (100%) through a nasal cannula, causing a low level of positive airway pressure; while speculative, it is believed that this strategy can improve the efficiency of respiratory muscles, resulting in decreased oxygen consumption and requirement, reduced BLa concentration and improved perceptions of recovery.[8, 45] In the study by Argus and colleagues,[8] participants were required to perform three bouts of 30s maximal sprint cycling, using a preload of 60s cycling at 4.5 W/Kg and 20-mins recovery between each bout. It was identified that HUM attenuated the decrement in mean power over the three exercise bouts when compared with a passive control (2.2 ± 2.5 %, *likely beneficial*). In conjunction with an improvement in power measures, HUM was able to reduce BLa levels during the recovery period (4.3 ± 7.9 %, *possibly beneficial*). Again, while a placebo effect may be responsible for the results observed, a belief questionnaire was used to attempt to control for a placebo effect. Only 2/8 participants accurately predicted the most effective recovery strategy therefore indicating that a placebo effect may not have been present. While further research is necessary to support the current findings, HUM appears a worthwhile tool for cyclists to increase anaerobic power measures and enhance recovery when there is a short turnaround between cycling events.

Table 7. Summary of Studies Examining the Use of Humidification Therapy Post-exercise in Cyclists.

Study	**Sample/ Training Status/ Sample Size**	**Exercise Protocol**	**Recovery Strategy & Duration**	**Markers of Recovery/ Performance**	**Results**	**Overall**
Argus et al, 2013[8]	Highly trained cyclists (A/B grade) N = 11	Pre: 30s max sprint cycling (S1) with 60s preload @ 4.5W/Kg Post 1 (S2) & Post 2 (S3): 30s max sprint cycling with 60s preload @ 4.5W/Kg	COMP (calf: 27 ± 6 mmHg; thigh: 18 ± 2 mmHg) EMS (15.7 ± 2.8 Hz) HUM Passive (CON) Duration: 2 x 20-mins between bouts (R1 & 2)	30s cycling mean power BLa TQR Belief	COMP attenuated ↓ mean power vs CON S1 – S2 (0.8 ± 1.2 %, *possibly beneficial*) & S1 – S3 (1.2 ± 1.9 %; *possibly beneficial*) HUM attenuated ↓ mean power vs CON from S1 – S3 (2.2 ± 2.5 %, *likely beneficial*) COMP no sig dif BLa or TQR vs CON ($p > 0.05$) HUM & EMS ↓ R2 BLa vs CON (HUM: 4.3 ± 7.9 %, *possibly beneficial*, EMS: 4.9 ± 6.9 %, *possibly beneficial*) EMS ↑ R2 TQR vs CON (0.7 ± 0.9, *likely beneficial*) 2 / 8 participants accurately predicted which strategy would enhance their recovery (belief).	COMP & HUM > CON attenuating ↓ mean power COMP & CON = BLa & TQR HUM & EMS > CON ↓ BLa EMS > CON ↑ TQR Possibly no placebo effect (2/8 belief)

N number of cyclists, *W/Kg* watts per kilogram of bodyweight, *COMP* compression garments/full length tights, *EMS* electromyostimulation/electronic muscle stimulation, *HUM* humidification therapy, *CON* control condition/passive rest, *R1 & 2* recovery one and recovery two, *BLa* blood lactate concentration, *TQR* perceived total quality recovery.

Sports Massage (SM)

Sports massage is commonly used to attenuate muscular fatigue[46] and it is believed that through sports massage, there is an increase in blood flow which assists in the removal of metabolic waste.[47] Additionally, sports massage with ozonized oil (SMOZO) (30% ozonized sunflower seed oil with 0.5% alpha-lipoic acid) has been shown to promote local microcirculation, cellular oxygen uptake and stimulate oxidative defensive enzymatic systems, which could further enhance recovery.[48] In the study by Paoli and colleagues,[48] SMOZO increased PPO following anaerobic cycling when compared with SM alone and a control condition (SMOZO: 370 ± 60 W, SM: 340 ± 55 W, CON: 344 ± 56 W, $p < 0.05$). When comparing SM and a passive control, Bielik and colleagues[46] revealed no statistically significant difference (CON: 876 ± 56 W, SM: 922 ± 51 W, $p > 0.05$) albeit, there was a 46W difference between conditions and had an effect size analysis been conducted, perhaps an effect would have been observed. Interestingly in a study by Monedero & Donne,[49] SM resulted in a 7.7 ± 1.5 second increase in subsequent 5-km TT performance time, passive rest resulted in a greater 9.9 ± 1.6 second increase and a combination of both active recovery and SM was the most effective strategy, resulting in only a 2.9 ± 1.5 second increase in subsequent performance time ($p < 0.01$). Due to the aforementioned potential mechanism for SM to increase the removal of metabolic waste, one would expect a consistent improvement in BLa from the use of SM. Nevertheless, results are confounding with CON shown to be more beneficial at reducing BLa 15-mins post exercise[47] and AR shown to be more beneficial than SM at reducing BLa post-recovery (table 8).[46, 47, 49] Consistent with performance results, both SMOZO and a combination of AR and SM, prove more effective than both SM alone and a passive rest control at reducing BLa.[48, 49]

Psychologically, SM both with and without ozonised oil was more beneficial than passive rest at reducing perceived fatigue[48] nevertheless, SM with ozonised oil was still more effective than SM alone. SM was more beneficial than AR at reducing HR measures[46, 49] but also revealed no difference when compared with a passive control or SMOZO.[48] While more research is necessary to support the current findings, it appears that SM, SMOZO and a combination of AR and SM are more effective than passive rest at improving recovery and subsequent performance.

Table 8. Summary of Studies Examining the Use of Sports Massage Post-exercise in Cyclists.

Study	Sample/ Training Status/ Sample Size	Exercise Protocol	Recovery Strategy & Duration	Markers of Recovery/ Performance	Results	Overall
Bielik, 2010[46]	Junior elite Slovakian off-road cyclists (age = 19 ± 1 years; VO_{2max} = 67 ± 3 mL·Kg^{-1}·min^{-1}) N = 11	Pre: 3 x 30s WAnT (s1-3) with 4-min recovery between intervals Post: 30s WAnT (s4)	Passive recovery (CON) SM AR (10-mins @ 20% VO_{2max} and 10-mins @ 40% VO_{2max}) Duration: 20-mins	PPO Mean power Fatigue index % BLa $HR_{recovery}$	No sig dif PPO SM vs CON (CON: 876 ± 56 W, SM: 922 ± 51 W, $p > 0.05$) AR ↑ PPO (CON: 876 ± 56 W, AR: 970 ± 69 W, $p < 0.05$) and mean power output (CON: 678 ± 45, AR: 746 ± 47 W, $p < 0.05$) vs CON No sig dif mean power SM vs CON (CON: 678 ± 45 W, SM: 715 ± 33 W, $p > 0.05$) No sig dif fatigue index between conditions (% change in power output between the first 5s and last 5s of the 30 second exercise period) (CON: 34 ± 8 %, SM: 33 ± 7 %, AR: 35 ± 8%) AR ↓ BLa vs CON and SM post-recovery (CON: 13.31 ± 2.9 mmol·L^{-1}, AR: 7.49 ± 3.9 mmol·L^{-1}, SM: 14.68 ± 3.0 mmol·L^{-1}, $p < 0.01$) AR ↑ $HR_{recovery}$ vs CON and SM (CON: 105 ± 9 b·min^{-1}, AR: 125 ± 12 b·min^{-1}, SM: 104 ± 8 b·min^{-1}, $p < 0.01$)	AR > CON ↑ PPO & mean power AR > CON & SM ↓ BLa post-recovery AR > CON and SM ↑ $HR_{recovery}$

Paoli et al, 2013[48]	Male competitive amateur cyclists (age = 27 ± 3.5 years; training years = 8 ± 4 years) N = 15	Pre: 3 x 30s WAnT with 2-mins recovery between intervals Post: Ramp test until voluntary termination (3-min baseline cycling @ 60W + 30W·min^{-1} ↑ thereafter)	Passive rest (CON) Sports massage with Bioperoxoil (SMOZO) [30% ozonised sunflower seed oil with 0.5% alpha-lipoic acid] Sports massage (SM) Duration: 5-mins passive seated on bike followed by 16-mins per condition (~8-min prone and ~8-min supine for all conditions)	BLa $HR_{recovery}$ Ramp test PPO Perceived fatigue	SMOZO ↓ BLa vs SM & CON 13-mins post exercise when compared with immediately post-exercise (SMOZO: -34.3 %, SM: -22.5 %, CON: -25.4 %) and at 20-mins when compared with 13-mins post exercise (SMOZO: -27.6 %, SM: -27.2 %, CON: -23.2 %) No sig dif $HR_{recovery}$ between conditions ($p > 0.05$) SMOZO ↑ PPO vs SM & CON (SMOZO: 370 ± 60 W, SM: 340 ± 55 W, CON: 344 ± 56 W, $p < 0.05$) SMOZO & SM ↓ perceived fatigue vs CON ($p < 0.033$) SMOZO ↓ perceived fatigue vs SM ($p < 0.033$)	SMOZO > SM & CON ↓ BLa SMOZO, SM & CON = HR SMOZO > SM & CON ↑ PPO SM with and without ozonised oil > CON ↓ perceived fatigue SMOZO > SM ↓ perceived fatigue
Martin et al, 1998[47]	Competitive male cyclists (age = 24.5 ± 3.98 years; VO$_{2max}$ = 55.87 ± 3.82 mL·Kg^{-1}·min^{-1}) N = 10	Pre: 3 x 30s WAnT with 2-mins passive rest between intervals	Sport massage (SM) AR (80rpm @ 40% VO$_{2max}$) Passive lying in a supine position (CON) Duration: 20-mins	BLa	AR significantly ↓ BLa post-recovery vs SM & CON (AR: -59.38 %, SM: -36.21 %, CON: -38.67 %) CON ↓ BLa vs SM 15-mins post exercise ($p < 0.05$) but not at 20 or 25-mins	AR > SM & CON ↓ BLa CON > SM ↓ BLa 15-mins post exercise

Monedero & Donne, 2000[49]	Trained male cyclists (age = 25 ± 1 years; VO_{2max} = 68 ± 1.7 $mL\cdot Kg^{-1}\cdot min^{-1}$; PPO = 364 ± 9 W; training years = 5 ± 0.3 years) N = 18	Pre & post: 5-km maximal effort cycling test	Passive seated at rest (CON) AR (50% VO_{2max}) SM (lower leg) Combined [AR & SM] (3.75min AR @ 50% VO_{2max} pre and post-SM, 7.5min SM) Duration: 15-mins	5-km performance time BLa $HR_{recovery}$	Combined attenuated ↓ performance time vs CON, AR & SM (performance time increase between 1st and 2nd test; CON: 9.9 ± 1.6 seconds, AR: 6.9 ± 1.3 seconds, SM: 7.7 ± 1.5 seconds, combined: 2.9 ± 1.5 seconds, $p < 0.01$) Combined ↓ BLa vs CON & SM ($p < 0.01$) CON, SM & SM portion of combined ↓ $HR_{recovery}$ vs AR & AR portion of combined during recovery ($p < 0.05$)	Combined > CON, AR & SM attenuating ↓ 5km performance time Combined & AR > CON & SM ↓ BLa CON & SM > AR ↓ $HR_{recovery}$

VO_{2max} maximal oxygen uptake, *N* number of cyclists, *WAnT* wingate anaerobic cycling test, *SM* sports massage, *AR* active recovery, *PPO* peak power output, *BLa* blood lactate concentration, *HR* heart rate, *CON* control condition/passive rest, *SMOZO* sports massage with ozonised oil, *W* watts.

Static Stretching (SS)

To our knowledge, the current research evaluating static stretching (SS) on cyclists using a cycling exercise protocol is limited to one study (table 9).[50] SS, while beneficial for increasing range of motion (RoM), has been shown to temporarily decrease muscular power.[51, 52] In the study by Kingsley and colleagues,[50] SS resulted in no significant difference for any of the performance variables measured when compared with quiet rest (QR). Unfortunately, the details of how QR were performed was not described. While no significant difference was observed, SS resulted in a 0.86% increase in absolute PPO when compared with QR. SS increased relative peak power output (+0.86 %) and peak $r \cdot min^{-1}$ (+1.90 %) when compared with QR, but again, no significant difference was observed ($p > 0.05$). The use of Cohen's *d* effect size analysis would have been a worthwhile tool to better evaluate the findings of the current study. As expected, SS improved RoM and resulted in a 2.1cm increase in sit and reach distance ($p < 0.05$). With limited research, it is difficult to interpret the efficacy of SS. However, based on the current evidence it can be deduced that SS does not inhibit anaerobic cycling power if used for 3 x 30s per muscle and is a worthwhile inclusion where RoM is limited and an increase in RoM will prove advantageous to performance. Indeed, cycling has been linked to increased quadriceps muscle group, hamstrings muscle group and ITB tightness; which have been suggested to increase force on the knee and the potential for injury.[53] Therefore performing quadriceps, hamstring and ITB stretching between exercise bouts could be beneficial.

Table 9. Summary of Studies Examining the Use of Static Stretching Post-exercise in Cyclists.

Study	Sample/ Training Status/ Sample Size	Exercise Protocol	Recovery Strategy & Duration	Markers of Recovery/ Performance	Results	Overall
Kingsley et al, 2013[50]	Aerobically trained cyclists (age = 21 ± 2 years; VO_{2max} = 42.0 ± 5.6 mL·Kg^{-1}·min^{-1}) M = 9 F = 4	Pre: 30-min cycling @ 65% VO_{2max} Post: 30s WAnT	SS (3 x 30s per leg: Hamstrings, quadriceps, hip flexors and extensors & piriformis) QR (details not described) Duration: 15-mins	Sit & reach Absolute PPO Relative PPO RPM_{peak}	SS ↑ Sit & reach from 25.2 ± 2.2 cm to 27.3 ± 1.7 cm ($p < 0.05$) No sig dif between conditions for any performance variable ($p > 0.05$) SS ↑ absolute PPO vs QR but no sig dif (+0.86 %, $p > 0.05$) SS ↑ relative PPO vs QR but no sig dif (+0.86 %, $p > 0.05$) SS ↑ RPM_{peak} vs QR but no sig dif (+1.90 %, $p > 0.05$)	SS & QR = Absolute PPO, relative PPO & RPM_{peak}

VO_{2max} maximal oxygen uptake, *WAnT* wingate anaerobic cycling test, *SS* static stretching, *QR* quiet rest, *PPO* peak power output, *RPM* cycling revolutions per minute.

Active Recovery (AR)

Active recovery can be described as gentle exercise between exercise bouts; believed to enhance metabolic waste removal and improve subsequent performance.[39] With varying methods used in cycling literature (table 11), it is difficult to discern the optimal exercise intensity and duration for improving subsequent cycling performance (table 10). Connolly and colleagues[54] discovered that AR used for 3-mins following 15s sprint cycling and repeated 6 times, resulted in an attenuation of the decrement in mean power when compared with a passive control ($p < 0.002$, $F = 4.78$). The use of AR in an anaerobic setting was further supported by Bielik and colleagues[46] who identified that AR following 3 x 30s WAnT with 4-min recovery between intervals was able to significantly increase PPO (CON: 876 ± 56 W, AR: 970 ± 69 W, $p < 0.05$) and mean power output (CON: 678 ± 45, AR: 746 ± 47 W, $p < 0.05$) in the following 30s cycling WAnT. The ability for AR to attenuate a decrement in subsequent performance is not limited to anaerobic power and has been shown beneficial when implemented between 5-km TT cycling bouts, with a performance time increase between pre and post 5-km TT tests of 6.9 ± 1.3 sec; where CON resulted in a greater increase of 9.9 ± 1.6 sec.[49] Unfortunately, further studies examining AR in cycling either did not use a passive control and compared AR against CWI, or they simply did not examine a subsequent performance bout.[31, 32, 39, 47] Comparing against CWI makes it difficult to interpret performance findings, as CWI has been shown to improve subsequent performance when compared with passive rest.[9, 30, 34]

AR was able to attenuate BLa concentration by around 21-54% more than that of passive rest. [46, 47, 49] However, one study revealed no significant difference in BLa levels following AR[54] (AR: 9.09 ± 2.37 $\text{mmol}\cdot\text{L}^{-1}$, CON: 10.05 ± 2.84 $\text{mmol}\cdot\text{L}^{-1}$; p

= 0.37) and this could have been due to a shorter recovery duration of only 3-min intervals.[54] The authors from this study hypothesised that perhaps measuring plasma lactate concentration as opposed to intracellular lactate concentration was not an effective method of assessing BLa given the short rest duration. It comes as no surprise that AR increases HR to a great degree than passive rest during recovery and this increase in HR, may be one of the contributing factors as to why AR is beneficial to post-exercise recovery.[46, 49] It is theorised that an increase in HR, concomitant increase in blood flow and metabolic rate, are all factors which lead to improved recovery and performance.[46] A novel form of AR has been examined by performing active recovery in water (ARW).[55] Results indicated that ARW was more effective than passive recovery on land (PRL) and passive recovery in water (PRW) at reducing BLa concentration 15-60mins during recovery. Additionally, there was no change in HRV between conditions. However, when examining shorter resting protocols of up to 30-mins between exercise bouts, PRW and PRL appear more effective than ARW at improving HRV. Unfortunately no performance variables were examined.

The current literature supports the use of AR as an effective strategy to increase both recovery and exercise performance in cyclists. Future research should ensure that a passive rest control condition is used and that subsequent performance is examined, to support the current body of evidence. ARW is a novel recovery strategy that warrants further research. Future studies should compare ARW with AR on land and examine performance in conjunction with physiological variables.

Table 10. Different Exercise Intensities and Durations Utilised During Active Recovery Studies.

Author	Intensity	Duration	Control Condition	Subsequent Performance
Connolly et al., 2003[54]	80rpm (1Kg resistance)	3-mins	Yes	+
Joanna Vaile et al., 2008[31]	40% VO_{2max}	15-mins	No	-
Vaile et al., 2011[32]	40% PPO	15-mins	No	-
Chan et al., 2016[39]	40% PPO	15-mins	No	=
Monedero & Donne, 2000[49]	50% VO_{2max}	15-mins	Yes	+
Martin et al., 1998[47]	40% VO_{2max} / 80rpm	20-mins	Yes	n/a
Bielik, 2010[46]	20% VO_{2max} 40% VO_{2max}	10-mins 10-mins	Yes	+

+ Positive/enhanced, = no change, - negative/detrimental, *n/a* not measured/not applicable.

Table 11. Summary of Studies Examining the Use of Active Recovery Post-exercise in Cyclists.

Study	Sample/ Training Status/ Sample Size	Exercise Protocol	Recovery Strategy & Duration	Markers of Recovery/ Performance	Results	Overall
Connolly et al, 2003[54]	Recreationally active male cyclists (age = 21.8 ± 3.3 years) N = 7	Pre & Post: 6 x 15s sprint cycling with recovery protocol between intervals	AR (80rpm @ 1Kg resistance) x 3-mins Passive seated on bike (CON) x 2.50s	Mean PPO Mean power BLa	AR attenuated ↓ in mean PPO vs CON ($p < 0.002$, F = 4.78) Mean power no sig dif between conditions ($p = 0.57$) BLa no sig dif between conditions (AR: 9.09 ± 2.37 $mmol{\cdot}L^{-1}$, CON: 10.05 ± 2.84 $mmol{\cdot}L^{-1}$; $p = 0.37$)	AR > CON attenuating ↓ mean PPO AR & CON = mean power & BLa
Bielik, 2010[46]	Junior elite Slovakian off-road cyclists (age = 19 ± 1 years; VO_{2max} = 67 ± 3 $mL{\cdot}Kg^{-1}{\cdot}min^{-1}$) N = 11	Pre: 3 x 30s WAnT (s1-3) with 4-min recovery between intervals Post: 30s WAnT (s4)	Passive recovery (CON) SM AR (10-mins @ 20% VO_{2max} and 10-mins @ 40% VO_{2max}) Duration: 20-mins	PPO Mean power Fatigue index % BLa $HR_{recovery}$	No sig dif PPO (CON: 876 ± 56 W, SM: 922 ± 51 W, $p > 0.05$) and mean power (CON: 678 ± 45 W, SM: 715 ± 33 W, $p > 0.05$) SM vs CON AR ↑ PPO (CON: 876 ± 56 W, AR: 970 ± 69 W, $p < 0.05$) and mean power output (CON: 678 ± 45, AR: 746 ± 47 W, $p < 0.05$) vs CON No sig dif fatigue index between conditions (% change in power output between the first 5s and last 5s of the 30 second exercise period) (CON: 34 ± 8 %, SM: 33 ± 7 %, AR: 35 ± 8 %) AR ↓ BLa vs CON and SM post-recovery (CON: 13.31 ± 2.9 $mmol{\cdot}L^{-1}$, AR: 7.49 ± 3.9 $mmol{\cdot}L^{-1}$, SM: 14.68 ± 3.0 $mmol{\cdot}L^{-1}$, $p < 0.01$) AR ↑ $HR_{recovery}$ vs CON and SM (CON: 105 ± 9 $b{\cdot}min^{-1}$, AR: 125 ± 12 $b{\cdot}min^{-1}$, SM: 104 ± 8 $b{\cdot}min^{-1}$, $p < 0.01$)	AR > CON ↑ PPO & mean power AR > CON & SM ↓ BLa post-recovery AR > CON and SM ↑ $HR_{recovery}$

Martin et al, 1998[47]	Competitive male cyclists (age = 24.5 ± 3.98 years; VO_{2max} = 55.87 ± 3.82 $mL \cdot Kg^{-1} \cdot min^{-1}$) N = 10	Pre: 3 x 30s WAnT with 2-mins passive rest between intervals	Sport massage (SM) AR (80rpm @ 40% VO_{2max}) Passive lying in a supine position (CON) Duration: 20-mins	BLa	AR significantly ↓ BLa post-recovery vs SM & CON (AR: -59.38 %, SM: -36.21 %, CON: -38.67 %) CON ↓ BLa vs SM 15-mins post exercise ($p < 0.05$) but not at 20 or 25-mins	AR > SM & CON ↓ BLa CON > SM ↓ BLa 15-mins post exercise
Monedero & Donne, 2000[49]	Trained male cyclists (age = 25 ± 1 years; VO_{2max} = 68 ± 1.7 $mL \cdot Kg^{-1} \cdot min^{-1}$; PPO = 364 ± 9 W; training years = 5 ± 0.3 years) N = 18	Pre & Post: 5-km maximal effort cycling test	Passive seated at rest (CON) AR (50% VO_{2max}) SM (lower leg) Combined [AR & SM] (3.75min AR @ 50% VO_{2max} pre and post-SM, 7.5min SM) Duration: 15-mins	5-km performance time BLa $HR_{recovery}$	Combined attenuated ↓ performance time vs CON, AR & SM (performance time increase between 1st and 2nd test; CON: 9.9 ± 1.6 seconds, AR: 6.9 ± 1.3 seconds, SM: 7.7 ± 1.5 seconds, combined: 2.9 ± 1.5 seconds, $p < 0.01$) Combined ↓ BLa vs CON & SM ($p < 0.01$) CON, SM & SM portion of combined ↓ $HR_{recovery}$ vs AR & AR portion of combined during recovery ($p < 0.05$)	Combined > CON, AR & SM attenuating ↓ 5km performance time Combined & AR > CON & SM ↓ BLa CON & SM > AR ↓ $HR_{recovery}$

Chan et al, 2016[39]	Junior elite male cyclists (age = 16 ± 1 year; VO_{2max} = 64.7 ± 4.3 mL·Kg^{-1}·min^{-1} N = 8	Pre: 15-mins cycling @ 75% PPO & 15-min TT in heat (TT1, 31°C, 74% rh) Post: 15-mins cycling @ 75% PPO & 15-min TT in heat (TT2, 31°C, 74% rh)	CWI (15°C, mid-sternum level) CCT (15 °C, ankle and thigh of both legs, rhythmic compression setting HIGH) AR @ 40 % PPO (31°C) Duration: 10-mins passive seated in heat (31°C, 74% rh) 15-mins per condition 30-mins passive seated in heat	Mean power Core body temperature BLa RPE $HR_{recovery}$	No sig dif TT2 mean power between conditions (p = 0.551) CWI ↓ core body temperature 15-mins during recovery vs CCT (p = 0.011) CWI ↓ core body temperature vs AR post-recovery (p = 0.033) AR ↓ BLa vs CCT & CWI (AR: -75%, CCT: -62%, CWI: -62%) No sig dif RPE between conditions No sig dif $HR_{recovery}$ between conditions (p = 0.178)	CCT, CWI & AR = mean power, RPE & $HR_{recovery}$ CWI > CCT ↓ core body temperature post treatment CWI > AR ↓ core body temperature post-recovery AR > CWI & CCT ↓ BLa

Vaile et al, 2008[31]	Well-trained male cyclists (age = 32 ± 5 years; VO_{2max} = 70.7 ± 7.9 $mL \cdot Kg^{-1} \cdot min^{-1}$) N = 10	Pre (Ex1): 30-min cycling in heat (34 ± 0.2°C, 39.4 ± 1.5 % rh, 15-min @ 70% PPO and a 15-min maximal cycling TT) Post (Ex2): 30-min cycling in heat (34 ± 0.2°C, 39.4 ± 1.5 % rh, 15-min @ 70% PPO and a 15-min maximal cycling TT)	Shoulder height for all CWI conditions Intermittent CWI, 10°C (ICWI10) Intermittent CWI, 15°C (ICWI15) Intermittent CWI, 20°C (ICWI20) Continuous CWI, 20°C, in bath for entire 15-mins (CCWI20) AR (15-mins @ 40% VO_{2max}, 31.1 ± 2.6°C) Duration: Intermittent CWI = 5 x 1-min in bath, 2-mins out of bath (29.2 ± 1.4°C, 58 ± 2.1 % rh) 15-mins total per condition 40-mins passive recovery (34 ± 0.2°C, 39.4 ± 1.5 % rh)	30-min cycling total work (kJ) Body temperature BLa RPE $HR_{post-intervention}$ $HR_{post-recovery}$	AR ↓ Ex2 30-min cycling total work vs Ex1 (-4.1 ± 1.8 %, $p = 0.00$). All CWI conditions maintained total work vs AR ($p < 0.05$). ICWI 15°C ↑ total work Ex1 vs Ex2 but no sig dif (Ex1: 498 ± 47 kJ, Ex2: 500 ± 46 kJ, $p > 0.05$) No sig dif between CWI conditions for total work ($p > 0.05$) All CWI conditions ↓ post-recovery body temperature vs AR (CWI10: 34.6 ± 0.6 ° C, CWI15: 35.3 ± 0.6 °C, CWI20: 36.5 ± 0.5 °C, CCWI20: 36.1 ± 0.2 °C, AR: 38.2 ± 0.4 °C, $p < 0.05$) AR ↓ BLa post-recovery vs all CWI conditions ($p < 0.05$) ICWI10, ICWI15 & CCWI20 ↓ RPE mid-way through both exercise tasks vs AR ($p < 0.05$) CWI no sig dif post-exercise RPE vs AR ($p > 0.05$) AR ↑ $HR_{post-intervention}$ vs all CWI conditions (ICWI10: 86 ± 12 $b \cdot min^{-1}$, ICWI15: 80 ± 7 $b \cdot min^{-1}$, CWI20: 81 ± 12 $b \cdot min^{-1}$, CCWI20: 81 ± 9 $b \cdot min^{-1}$, AR: 128 ± 7 $b \cdot min^{-1}$, $p < 0.001$) AR ↑ $HR_{post-recovery}$ vs ICWI10, ICWI15 & CCWI20 (ICWI10: 74 ± 13 $b \cdot min^{-1}$, ICWI15: 69 ± 8 $b \cdot min^{-1}$, CCWI20: 71 ± 8 $b \cdot min^{-1}$, AR: 87 ± 11 $b \cdot min^{-1}$,) but not ICWI20 (ICWI20: 80 ± 6 $b \cdot min^{-1}$)	All CWI conditions > AR maintaining total work and ↓ post-recovery body temperature AR > all CWI conditions ↓ BLa ICWI10, ICWI15, CCWI20 > AR ↓ RPE during exercise All CWI conditions & AR = RPE post-exercise AR > all CWI conditions ↑ $HR_{post-intervention}$ AR > ICWI10, ICWI15 & CCWI20 ↑ $HR_{post-recovery}$

Vaile et al, 2011[32]	Endurance trained male cyclists (age = 33.7 ± 4.7 years; VO_{2max} = 66.7 ± 6.1 $mL \cdot Kg^{-1} \cdot min^{-1}$ N = 10	Pre & post: 35-mins cycling in heat [32.8 ± 1.1 °C, 43.6 ± 1.8 % rh] (15-mins @ 70% PPO; 15-min TT)	CWI (15°C, shoulder height) AR @ 40% PPO (32.8 ± 1.1°C) Duration: 15-mins per conditions followed by Passive rest in a supine position for 40-mins (32.8 ± 1.1°C, 43.6 ± 1.8 % rh)	15-min TT total work performed (kJ) T_{re} Limb blood flow (arm blood flow, leg blood flow & leg to arm blood flow ratio) HR BLa	AR↓ total work performed (pre to post Δ: -1.8 ± -1.1 %) CWI ↑ total work performed (pre to post Δ: +0.10 ± 0.7 %) CWI ↓ T_{re} post-recovery and post-exercise ($p < 0.05$) CWI ↓ leg and arm blood flow vs AR during recovery and post-recovery CWI ↓ arm blood flow post-exercise vs AR ($p < 0.05$) CWI ↑ leg to arm blood flow ratio vs AR during recovery No sig dif post-exercise blood flow ratio between conditions CWI ↓ HR during and post recovery vs AR (CWI: 78 ± 15 $b \cdot min^{-1}$, AR: 90 ± 11 $b \cdot min^{-1}$, $p < 0.05$) CWI ↓ HR during first 5-mins of exercise vs AR AR ↓ BLa post-recovery vs CWI (CWI: 4.5 ± 1.2 mM, AR: 2.3 ± 0.8 mM, $p < 0.05$)	CWI > AR ↑ total work performed CWI > AR ↓ T_{re} , leg and arm blood flow during recovery CWI > AR ↑ leg to arm blood flow ratio during recovery CWI & AR = leg to blood flow ratio post-exercise CWI > AR ↓ HR AR > CWI ↓ BLa

Ferreira et al, 2011[55]	Cyclists (age = 26 ± 6 years) N = 10	Pre: 30s WAnT with a load ~7.5% bodyweight and 4 x 10s max sprints, 15s rest between intervals	PRW (in a swimming pool, horizontally with the help of floats) x 60-mins ARW (85% LA on Water Bike, 28-32°C) 30-mins + 30-mins PRW PRL x 60-mins (room temperature & humidity not stipulated)	BLa $HR_{recovery}$	No sig dif between PRW & PRL for all variables measured BLa no sig dif between conditions 5-mins during recovery ARW ↓ BLa vs PRW & PRL 15-60mins during recovery (60-min BLa results: ARW: 3.19 ± 0.62 $mmol·L^{-1}$, PRW: 4.71 ± 1.08 $mmol·L^{-1}$, PRL: 4.52 ± 1.23 $mmol·L^{-1}$, $p < 0.05$) ARW ↑ $HR_{recovery}$ 5-30mins during recovery but not 60-mins vs PRW & PRL ($p < 0.05$)	ARW > PRW & PRL ↓ BLa during recovery PRW & PRL > ARW ↓ $HR_{recovery}$ up to 30-mins during recovery but not 60-mins

N number of cyclists, *AR* active recovery, *CON* control condition/passive rest, *PPO* peak power output, *BLa* blood lactate concentration, *WAnT* wingate anaerobic cycling test, *SM* sports massage, *HR* heart rate, VO_{2max} maximal oxygen uptake, *TT* time trial, *CWI* cold water immersion, *CCT* cold compression therapy, *RPE* rating of perceived exertion, *rh* relative humidity, T_{re} rectal temperature, *PRW* passive recovery in water, *ARW* active recovery in water, *PRL* passive recovery on land.

Conclusion

Based on the current body of evidence, the use of COMP has been shown beneficial at improving subsequent mean and maximal cycling power.[6, 8, 26, 27] CWI used for 5-mins at 14°C following 25-mins of submaximal cycling has been shown to improve 4-km TT time to completion in the heat and average power output.[30] CWI used for 14-15mins at 15°C appears advantageous for improving 9-15min TT total work performed and repeated sprint power output.[31, 32, 34] CWI also appears to be more beneficial than AR at improving total work performed.[32] CWT used between 6-14mins with 38°C HWI and 15°C CWI and a ratio of cold:hot of 1:1-mins or 1:2-mins, has been shown to increase subsequent TT total work performed, TT & sprint mean power output and sprint PPO.[6, 34] This performance benefit from CWT has been observed from durations as short as a 15s sprint and up to a 15-min TT.[6, 34] HWI alone appears to be detrimental to performance,[34] while TWI has been shown to decrease 20-km TT time to completion and improve average cycling speed.[43] The use of HUM has been shown to attenuate the decrement in sprint mean power and EMS may be beneficial.[8] SMOZO could assist anaerobic cycling performance[48] and SM may improve anaerobic cycling mean power and reduce 5-km TT time to completion.[46, 49] A combination of recovery strategies should be explored further, as AR and SM combined, were more beneficial than AR or SM alone, at reducing 5-km TT time to completion.[49] The use of SS did not inhibit anaerobic cycling performance when performed for 3 x 30s per muscle and leg[50] and may be a useful strategy for improving RoM and reducing the risk of knee injury when performed on the quadriceps muscle group, hamstrings muscle group and I.T.B between cycling exercise bouts.[53] AR has been shown to attenuate 15s sprint PPO, 5km TT time to completion and even increase 30s sprint cycling mean power and PPO.[46, 49,

[54] The impact of ARW on performance should be examined and compared with AR on land.

Novel recovery strategies have been shown to positively impact recovery and subsequent exercise performance, and researchers should continue to build on the existing body of evidence while also seeking to explore new recovery strategies. Despite positive findings for the use of Intermittent Sequential Pneumatic Compression (ISPC)[56, 57] using a cycling protocol, there have yet to be any studies examining ISPC for recovery in cyclists and this is a worthwhile intervention to examine in future research. Therefore, given the gap identified in the current literature, the aim of the study in chapter two of this thesis was to investigate the use of ISPC when used between two cycling bouts in trained cyclists.

Chapter Two:

Pneumatic Compression Fails to Improve Performance Recovery in Trained Cyclists

*This chapter appears in the same format as it was accepted in the *International Journal of Sports Physiology and Performance*.

Abstract

Purpose: To examine the efficacy of Intermittent Sequential Pneumatic Compression (ISPC) on exercise recovery and subsequent performance, when implemented between a 20-min cycling bout (simulated scratch race) and a 4-min cycling test (simulated individual pursuit), as experienced during an Omnium track cycling competition. ***Methods:*** Twenty-one (13 male, 8 female, mean ± SD; age: 36 ± 14 years) trained cyclists completed a familiarisation trial followed by two experimental trials in a counterbalanced, crossover design. Participants performed a fixed-intensity 20-min cycling bout on a Wattbike cycle ergometer, followed by a 30-min recovery period where ISPC recovery boots or passive recovery (CON) was implemented. At the conclusion of the recovery period, participants performed a 4-min maximal cycling bout (4-minTT). Average power (Watts) for the 4-minTT, blood lactate concentration (BLa) and perceived total quality recovery (TQR) during the recovery period were used to examine the influence of ISPC. ***Results***: There were no significant differences between trials for the 4-minTT ($p = 0.08$), with the effect deemed to be *trivial* ($d = -0.08$). There was an *unclear* effect (d ±90%CI = 0.26 ±0.78, $p = 0.57$) for ISPC vs CON in the clearance of BLa during the recovery period. There was a *small* but not significant difference for TQR in favour of ISPC (d ±90%CI = 0.27 ±0.27, $p = 0.07$). ***Conclusion*:** There was little additional benefit associated with the use of ISPC to enhance recovery and subsequent performance when used during the recovery period between two events in a simulated Omnium track cycling competition.

Keywords: *Omnium, track cycling, fatigue, Recovery-boots, Wattbike*

Introduction

During congested competition schedules, like those often experienced at events such as the Olympic Games, recovery strategies are thought to alleviate post-exercise fatigue and enhance subsequent performance.[7, 8] The Omnium is a multi-race event in track cycling at the Olympic Games, with short periods of recovery (as little as 30-mins) between 6 separate races.[58] It is believed that events with brief periods of recovery such as the Omnium, create a substantial challenge for athletes and coaches to ensure optimal recovery is attained and has been one of the contributing factors for the development of acute recovery strategies aimed to enhance performance recovery.[8, 9] It has been suggested that the power decrement following 20-mins of time-trial cycling (similar to a scratch race in the Omnium) is related to metabolic acidosis.[59] Similarly, Bishop et al.,[60] have revealed that a warm up yielding blood lactate levels as low as $5 \text{mmol} \cdot L^{-1}$, resulted in impaired subsequent exercise performance in trained athletes. Therefore, strategies designed to mitigate the potentially deleterious effects of metabolic acidosis in this setting may be important for improving recovery between exercise bouts where time to recover is limited. Furthermore, recent research has suggested that there is a positive correlation between an increase in blood flow and performance recovery between bouts of high-intensity cycling exercise[61]. Therefore, methods to enhance blood flow following exercise could be advantageous.

Compression garments, or static compression, are thought to improve exercise recovery by enhancing venous return, and thereby assist in the removal of metabolic waste accumulated as a result of exercise.[8] More recently, athletes have incorporated the use of Intermittent Sequential Pneumatic Compression (ISPC), a form of dynamic compression, to enhance recovery post-exercise.[57] Similar to compression garments, ISPC derives from the medical sector where comparable devices have been used for the treatment of lymphedema and post-traumatic edema.[62, 63] ISPC however, differentiates from compression garments; by exerting up to 4-times greater levels of pressure (~80mmHg) to the applied area, when compared with commercially available compression garments.[64] Additionally, ISPC mimics the anatomical muscle-venous pump by providing a mechanical "squeezing" of the limb through inflatable cuffs/sleeves, from distal to proximal, in a sequential fashion.[57] This dynamic application of pressure has been shown superior when compared to uniform/static compression (constant application of pressure) at enhancing venous blood flow and may further increase the removal of metabolic waste when compared to static compression methods.[65].[65]

Research evaluating ISPC for exercise recovery and/or subsequent performance is limited and contradictory, with an array of methods used to assess its efficacy.[56, 57, 62, 63, 66, 67] Hanson et al.[57] and O'Donnell & Driller[62] discovered a trend towards improved blood lactate clearance following cycling exercise with the use of ISPC (60-80mmHg) during recovery when compared to a passive control. Hanson examined twenty-one female club level lacrosse and field hockey athletes, to reveal a statistically significant improvement in blood lactate clearance 20-mins following a 1-min maximal cycling ergometer sprint ($p = 0.04$). However, Hanson and colleagues did not report any performance measures, making it difficult to evaluate the efficacy of ISPC. This was further supported by O'Donnell & Driller[62] who reported a 94% positive likelihood and a *small* effect for improved blood lactate clearance 30-mins following a cycling interval session in well-trained triathletes.

However, the improved blood lactate clearance did not translate into significant findings between ISPC and passive recovery on subsequent 5-km treadmill run time following the cycling exercise ($p = 0.31$; $d = 0.07$). Similarly, Northey et al.,[66] exhibited no significant difference from the use of ISPC (30-mins at ~80mmHg) to attenuate subsequent performance in twelve strength-trained males following a fatigue-inducing weight-lifting session. The authors discovered that ISPC was unable to attenuate a decrement in isokinetic quadriceps torque, squat jump height and counter movement jump height. In addition to improved blood lactate clearance, Zelikovski et al,[56] and Wiener et al,[67] have both revealed improvements in subsequent performance with the implementation of ISPC when compared with a passive control. Zelikovski et al,[56] studied eleven untrained but physically active male participants performing two cycling bouts at 80% of predicted VO_{2max} until exhaustion and results revealed that a modified ISPC device (~50mmHg of pressure for 20-mins) increased time to exhaustion by 45% in the subsequent cycling bout. ISPC was also able to attenuate tibialis anterior fatigue in the study by Wiener et al[67] who examined 8 male participants during 10-mins of treadmill walking at maximum walking speed and 2-mins of quasi-isometric suspension by strapping ~10kg weights to both feet. The recovery protocol involved ISPC (3-mins at ~80mmHg) applied to one leg, while the other leg acted as a passive control. Electromyography revealed that ISPC significantly improved the mean power frequency of the tibialis anterior ($p < 0.05$).

With contrasting results and limited literature, further research is necessary to determine the value of ISPC on exercise recovery and/or subsequent performance. While ISPC has been examined in cycling settings, studies have failed to examine these effects in trained cyclists, limiting the ecological validity of their results. Therefore, the current study aimed to examine the impact of ISPC on trained cyclists, when implemented between a maximal 20-min cycling bout (simulated scratch race) and a 4-min maximal test (simulated individual pursuit), as experienced during an Omnium track cycling competition. Indeed, the individual pursuit has been previously identified as being one of the key determinants of overall success in elite Omnium competition[58, 68], and therefore, recovery from the previous event (scratch race) in the Omnium schedule, and the combination of these two events is of utmost importance to overall performance in the Omnium.

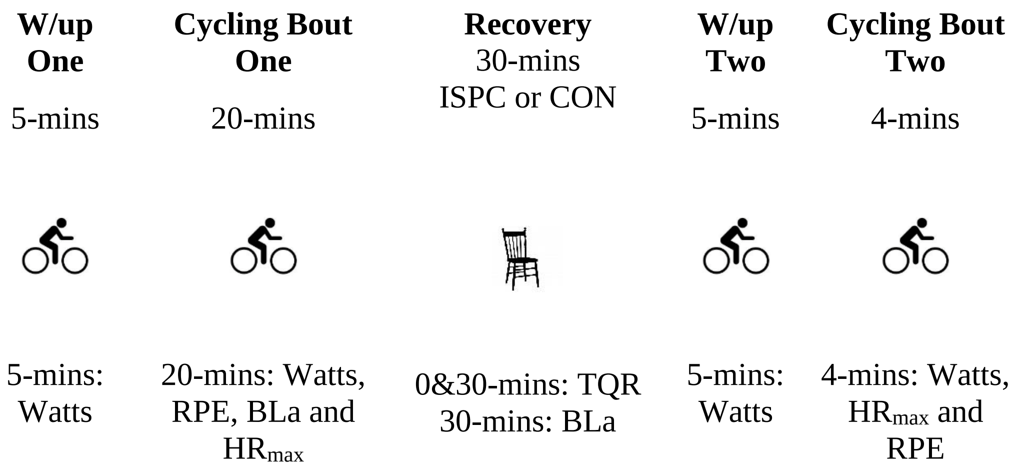
Methodology

Participants

Twenty-one trained cyclists with an average of 7 years track racing experience and 9 years road racing experience (male = 13, female = 8, mean ± SD; age: 40 ± 14 and 29 ± 12 years , respectively; VO_{2max}: 50 ± 10 $ml \cdot kg^{-1} \cdot min^{-1}$ and 46 ± 5 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively), partaking in a minimum of 3 cycling sessions, for >30-mins per week volunteered to participate in the current study. The majority of participants (n=19) were regularly competing in track cycling races each week, where Omnium type events were simulated. All participants provided informed written consent before taking part and ethical approval for the study was obtained from the institutions Human Research Ethics Committee.

Design

The current study involved participants attending a sport science laboratory for 3 separate trials over a 3-week period. To mitigate a learning effect, participants initially performed a familiarisation trial of the testing protocol, which was to be used in the experimental trials. Following the familiarisation trial, in a randomised, counterbalanced, crossover design, participants performed two trials separated by >48 hours and <7 days. During the recovery protocol participants were assigned to either Intermittent Sequential Pneumatic Compression (ISPC) or passive recovery/control (CON). Participants were required to keep training the same for both testing weeks and instructed to avoid high intensity training <24-hrs prior to testing. All testing was performed on the same cycle ergometer (Wattbike Ltd, Nottingham, UK) and at the same time of day (± 1 hour), to minimise diurnal variation. Participants personal bicycle seat and handle-bar measurements were replicated on the Wattbike. The reliability of the Wattbike has been reported previously over a range of power outputs (50-300W), with a mean CV of 2.6% (95% CI 0.7-2.0%) in trained cyclists.[69] To control for variability in nutrition, participants completed a 24-hr food diary and were instructed to replicate food and drink consumed for the subsequent trial. Participants were notified to refrain from caffeine (< 12 hours) and to arrive in a hydrated state. The exercise protocol used in the current study (fig 1.) was selected to closely mimic the 2016 Olympic Games schedule for the Omnium track-cycling event, simulating two of the six cycling races (scratch race and individual pursuit), with the scheduled recovery period between each race.



W/up One	**Cycling Bout One**	**Recovery** 30-mins ISPC or CON	**W/up Two**	**Cycling Bout Two**
5-mins	20-mins		5-mins	4-mins
5-mins: Watts	20-mins: Watts, RPE, BLa and HR_{max}	0&30-mins: TQR 30-mins: BLa	5-mins: Watts	4-mins: Watts, HR_{max} and RPE

Figure 1. Experimental Protocol. Warm up was self-selected and replicated for both ISPC and CON trials. *W/up* warm up, *ISPC* Intermittent Sequential Pneumatic Compression, *CON* control/passive recovery, *Watts* watts/average power, *HR* heart rate, RPE rating of perceived exertion, *BLa* blood lactate, *TQR* perceived total quality recovery, HR_{max} maximum heart rate.

Procedures

Familiarisation Trial

The familiarisation trial simulated the exact conditions of the experimental trials. However, during the 4-min maximal cycling effort (4-minTT), a metabolic cart (Parvo Medics, TrueOne® 2400, Sandy, UT, USA) was used to assess maximal oxygen uptake (VO_{2max}) to characterise the training level of participants in the current study. The cart was calibrated using alpha gases according to manufacturers instructions. While measuring VO_{2max} during a 4-min test may not be the commonly accepted method of VO_{2max} assessment, shorter maximal cycling tests have been used previously and have been shown to produce similar results to incremental ramp VO_{2max} tests.[37, 70] Therefore, given VO_{2max} was used purely as an additional descriptor of participant characteristics, we opted for this method of testing. At the conclusion of the familiarisation trial and to provide insight for the likelihood of a placebo effect, participants were asked to indicate the degree to which they believed the recovery intervention would enhance their recovery using a visual analog scale.[29, 71] Participants were required to use a single vertical line to mark an unmarked horizontal line measuring 10-centimetres in length. Participants were only informed that 0cm, or the beginning of the line, meant they did not believe ISPC would enhance their recovery and the end of the line, or 10cm, indicated they were certain that ISPC would enhnace their recovery, as used previously.[29] Care was taken throughout the experimental period so as to not influence participants' perceptions to the efficacy of ISPC.

Maximal 20-min Cycling Bout (20-minTT)

Following a 5-min warm-up, participants performed 20-mins of maximal cycling on the Wattbike cycle ergometer, where average power, heart rate (Polar Electro Oy, Finland), blood lactate (Lactate Pro 2 Analyser, Shiga, Japan) and ratings of perceived exertion (Borg's 6-20 scale)[72] were recorded at the 20-min mark of the test. The only instruction given to participants' was to perform the entire effort as maximally as possible. Average power output from the 20minTT of the first experimental trial was replicated for the following experimental trial, this was to ensure the same level of pre-load/fatigue before the 4-min TT. Additionally, during the replicated trial, average power output at 5-min intervals of the 20-minTT were replicated in an attempt to control the pacing profile between trials. The 20-min test was selected to simulate the duration necessary for elite athletes to complete the scratch race in the Omnium.[58, 73] While the scratch race during competition often requires high-intensity surges, this can be somewhat variable from race-to-race, and therefore we opted to simulate a more even-paced time trial.

Recovery Protocol (30-mins)

Following cycling bout one (20-minTT), participants performed one of the two recovery conditions:

a) Passive recovery/control (CON) – participants remained seated for 30-mins in the same temperature-controlled laboratory used throughout the entire study (19.5 ± 1°C).

b) Intermittent Sequential Pneumatic Compression (ISPC) – participants remained in a seated position with pneumatic compression sleeves (Recovery Boots, Recovery Pump, L.LC, USA) fitted to each leg. The ISPC device was set to a pressure of 80mmHg, with a deflation time of 30-seconds, for a total duration of 30-mins, as used previously.[62, 66] Sleeves were fitted according to the manufacturers instructions and individuals were sized appropriately to ensure the leggings covered from the toes to the inguinal crease of the upper leg. Each of the four chambers on each leg were filled with air in a sequential order (distal to proximal) and remained full until all chambers were filled; upon which the device deflated. This process was repeated for the entire duration of the recovery period.

At 10, 20 and 30-mins, participants were required to rate their perceived recovery on the total quality recovery scale (TQR). The TQR scale ranged from 6 (very, very poor recovery) to 20 (very, very good recovery).[8] Two minutes following the recovery period; when the participant was seated on the ergometer ready for cycling bout two, blood lactate was re-assesed. Blood lactate was assessed via a capillary fingertip sample; which was analysed with a Lactate Pro 2 analyser (Shiga, Japan).

The reliability of the Lactate Pro 2 has been deemed appropriate for research and has been reported elsewhere.[74]

Kikuhime Pressure Measurement

In a selection of participants (n = 18) interface pressure between the skin and ISPC was measured; to assess the actual pressure applied to the Quadriceps muscle group. The Kikuhime pressure monitor (MediGroup, Melbourne, Australia) sensor was placed on the Vastus Medialis Oblique. The Kikuhime pressure monitor has been shown to be a valid (ICC = 0.99, CV = 1.1%) and reliable (CV = 4.9%) tool for use in the sport setting.[28]

Performance Test (4-minTT)

Following the recovery period, participants performed a brief warm-up (Figure 1) and then a 4-min maximal cycling test on the Wattbike cycle ergometer. During the cycling test, participants were blinded to their power output and could only see time remaining. Average power output, maximum heart rate and rating of perceived exertion were acquired at completion and used for analysis. The 4-min cycling test was used to assess subsequent performance and simulated the approximate duration of the individual pursuit in the Omnium event.[58] At the 2016 Olympic Games, the winning individual pursuit time during the Men's Omnium was 4:14.9s, with the top 3 athletes in the individual pursuit, finishing with the medals for the overall Omnium. As mentioned previously, the individual pursuit has been identified as a key determinant to overall Omnium success[58, 68]. Acceptable levels of reliability for the 4-min time trial on a Wattbike ergometer have been reported previously with a coefficient of variation of 2.3%.[75]

Statistical Analysis

Statistical analyses were performed using the Statistical Package for Social Science (V. 24.0, SPSS Inc., Chicago, IL). Descriptive statistics are shown as means ± standard deviation, unless stated otherwise. Normality of the data for all measures were verified visually with histograms and also by the Shapiro-Wilk test. A student's paired t-test was used to compare 4-min TT power, HR_{max} and RPE measures for ISPC and CON, with an alpha level set at ($p < 0.05$) for all analysis. Standardised changes in the mean of each measure were used to assess magnitudes of effects and were calculated using Cohen's *d* and interpreted using thresholds of 0.2, 0.5, 0.8 for *small, moderate and large,* respectively.[76] An effect size of 0.2 was considered the smallest worthwhile effect with an effect size of <0.2 considered *trivial*. The effect was deemed *unclear* if its 90% confidence interval overlapped the thresholds for *small* positive and negative effects.[77] A two-way repeated measures ANOVA was used to determine differences between trials for change in blood lactate and TQR pre and post the recovery period. A Generalized Estimation Equation was used to analyse the TQR data pre and post recovery. Data was then divided into two groups for analysis, according to whether participants had positive perceptions to the efficacy of ISPC for recovery prior to the study ('believers', ≥60% belief in the ability of ISPC to aid their recovery on a visual analogue scale) or neutral to negative perceptions ('non believers', <60% belief in efficacy), as used previously.[29]

Results

Mean pressure (± SD) applied by ISPC in a cohort of the study population (n=18), as identified using the Kikuhime pressure monitor, was 79.1 ± 6 mmHg.

There were no significant differences in power output (Watts) (Both CON and ISPC: 221 ± 50 W), mean HR (Both CON and ISPC: 167 ± 19 beats$\cdot$min^{-1}) HR$_{max}$ (CON: 174 ± 18 beats $\cdot$min^{-1}; ISPC: 176 ± 15 beats $\cdot$min^{-1}) or RPE (Both CON and ISPC: 16 ± 2) for the 20-minTT between ISPC and CON trials ($p > 0.05$).

There were no significant differences between ISPC and CON trials for average Watts and RPE for the 4-minTT ($p > 0.05$, Table 1). 4-minTT average Watts revealed a 5 ± 13 Watt mean difference in the ISPC trial. This difference was associated with a *trivial* effect size of 0.08 (Table 1).

There was an *unclear* effect and no statistically significant two-way interaction between ISPC and CON for pre to post recovery BLa concentration ($F(1,20) = .327$, $p = 0.57$, Table 2). There was a *small* effect size ($d = 0.27$) but no statistically significant two-way interaction between ISPC and CON for pre to post recovery TQR $p = 0.07$, Table 2).

Maximum heart rate was significantly higher in ISPC when compared to CON at the end of the 4-minTT (178 ± 15 and 175 ± 14 bpm ± SD, respectively, p = 0.003, Table 1). This difference was associated with a *trivial* effect size ($d = 0.17$)

When separated for perceived ‘belief’ in ISPC and its effect on recovery, there were no significant differences ($p > 0.05$) between the ‘believers’ (n=16) and ‘non-believers’ (n=5) (Figure 2). This difference was associated with a *trivial* effect size ($d = 0.19$).

Table 12. 4-min Maximal Cycling Performance (4-minTT) Results for Intermittent Sequential Pneumatic Compression (ISPC) and Control (CON) Trials and Effect Sizes for the Comparison of Differences Between Trials (±90% confidence intervals). # Represents significant difference ($p < 0.05$).

	ISPC (mean ± SD)	CON (mean ± SD)	ISPC - CON Effect size (±90%Cl)
4-minTT (*Watts*)	289 ± 64	284 ± 66	0.08 ±0.08 *trivial*
4-min Max Heart Rate (bpm)	178 ± 15	175 ± 14	0.17 ±0.09# *trivial*
4-min RPE (Borg's 6-20 scale)	19 ± 2	19 ± 2	0.00 ±0.22 *unclear*

Table 13. Pre and Post Recovery Measures for Intermittent Sequential Pneumatic Compression (ISPC) and Control (CON) Trials and Effect Sizes for the Comparison of the Change Between Trials (±90% confidence intervals). $^{\#}$ Represents significant difference ($p < 0.05$).

	ISPC (mean ± SD)		CON (mean ± SD)		ΔISPC - ΔCON Effect size (±90%Cl)
	Pre	Post	Pre	Post	
Blood Lactate ($mmol \cdot L^{-1}$)	10.8 ± 3.8	3.6 ± 2.4	10.8 ± 3.2	3.1 ± 0.9	0.26 ±0.78 *unclear*
Perceived Total Quality Recovery (*TQR*)	11 ± 2	17 ± 2	11 ± 2	16 ± 2	0.27 ±0.27 *small*

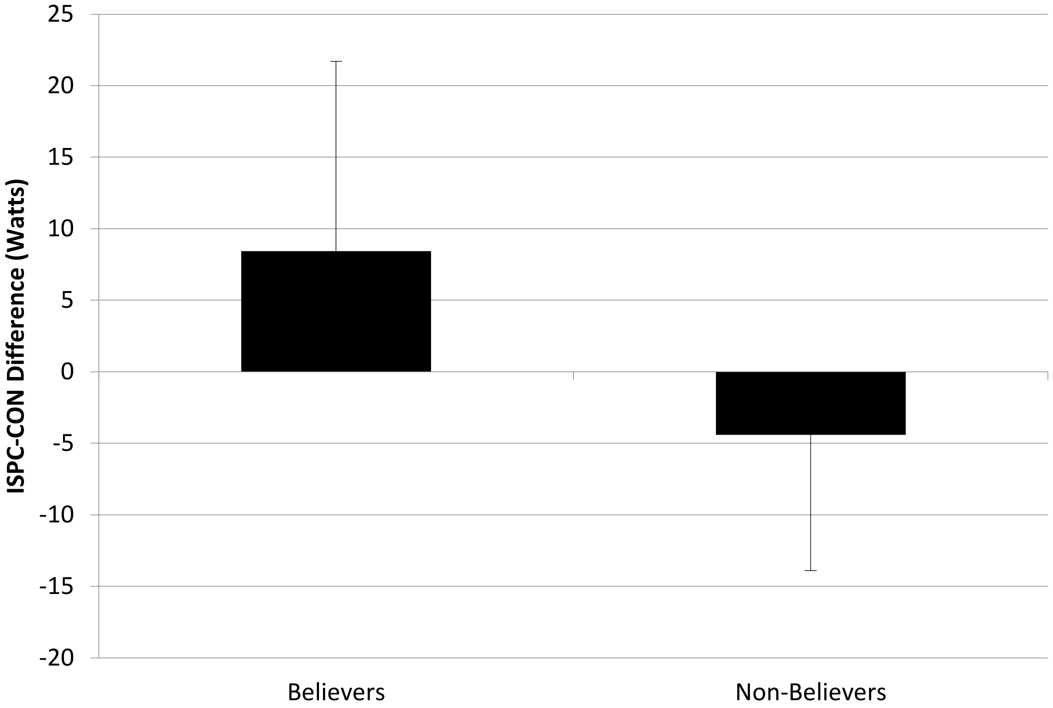


Figure 2. Mean Difference (±SD) Between ISPC (Intermittent Sequential Pneumatic Compression) and CON (passive recovery) for the 4minTT (Watts) for 'Believers' (n=16) and 'Non-believers' (n=5). *d* = 0.17, *trivial.*

Discussion

Results from the current study suggest that the use of ISPC does not enhance performance recovery when compared to passive recovery. While the use of ISPC improved 4-minTT cycling performance by ~5W when compared to passive recovery, this outcome was not statistically significant and resulted in a *trivial* effect size. Blood lactate and perceived TQR revealed no significant difference, although, a trend towards improved TQR ratings from the use of ISPC was observed with a *small* effect size when compared with CON for pre to post TQR.

The performance results of the current study are in agreement with the findings from both O'Donnell & Driller[62] and Northey et al,[66] who revealed no difference for subsequent performance from the use of ISPC when compared with passive recovery and are in contrast to Zelikovski et al,[56] & Wiener et al,.[67] As previously suggested,[62] the performance differences observed could be attributed to the use of an untrained population in the latter studies. Trained populations yield faster recovery rates between exercise bouts when compared to their untrained counterparts.

BLa concentration in the current study were also consistent with that of O'Donnell & Driller[62] and Zelikovski et al,[56] who revealed no significant differences between ISPC and CON. Albeit, O'Donnell & Driller[62] revealed a trend towards improved BLa concentration with a *small* effect, where the current study revealed an *unclear* effect. This trend for BLa clearance from the use of ISPC was further supported by Hanson and colleagues[57] who revealed a significant difference following 1-min maximal cycling. Unfortunately Hanson and colleagues[57] did not examine a subsequent performance measure, making it difficult to determine the effect of BLa on performance. TQR revealed no significant difference between trials, however, there was a trend for ISPC enhancing TQR. This was evidenced by a *small* effect size (d = 0.27) in favour of ISPC when compared to CON. This result for perceived recovery is in agreement with O'Donnell and Driller[62], who revealed a 68% likelihood that ISPC was beneficial compared to CON.

Interestingly, results revealed a significant increase in HR_{max} at the completion of the 4-minTT and this difference resulted in an increase of 3bpm. This is similar to that of Zelikovski et al,[56] who saw an increase in HR_{max} of 8bpm with the use of a modified ISPC device.

Contrary to the study by Brophy-Williams et al,[29] this investigation did not reveal a significant difference when accounting for a psychological benefit from believing the intervention would enhance recovery (placebo effect). Studies examining 'belief' in a recovery intervention are limited, however, because the placebo effect is very difficult to account for in recovery research, the authors would suggest this is a worthwhile inclusion for future research.

Practical Applications

Findings from the current study suggest that ISPC does not improve simulated track cycling individual pursuit performance, if used during the recovery period following a simulated scratch race. A limitation of the current study was that we did not test this intervention on elite cyclists. High performance programmes are often reluctant to include an intervention that would deviate from their programme and elite athletes are somewhat difficult to obtain access to for research studies on novel strategies, therefore it has become commonplace to first test interventions on lesser trained individuals before replicating the studies in a higher-trained population. The current study examined just 2 of the 6 events in an Omnium event and did not include intermittent bursts of high-intensity cycling as can be observed when riders attack during a scratch race. We acknowledge that the design could have more closely mimicked the exact demands of the scratch race and the individual pursuit, however, in order to ensure internal validity, we opted for a more controlled simulation. Future research should employ the testing of recovery strategies during an actual Omnium event in highly-trained atheltes.

Conclusion

The current study has shown that ISPC was unable to enhance recovery when used for 30-mins between two cycling bouts (20-min maximal time-trial and a 4-min maximal test). While there was a *small* trend towards improved perceptions of recovery with ISPC, this failed to transfer to any differences in performance.

Our results are in agreement with other studies using similar ISPC recovery protocols. We would suggest there is little, if any, additional benefit in using ISPC to enhance performance recovery in this setting.

Acknowledgements

The authors would like to thank the cyclists who participated in this study. No external funding was received for this research.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Chapter Three:

Recommendations for Future Recovery Research in Cyclists

Summary

To better understand the effect of recovery modalities on cycling recovery and subsequent performance, future research might consider:

- The use of a pressure monitoring device (e.g. Kikuhime) when examining compression garments, to determine whether there is a relationship between garment pressure exerted and resultant benefits in cycling performance.
- The use of a visual analogue scale to examine ‘belief’ in the recovery intervention, with an attempt to better understand the placebo effect.
- Controlling the intensity of the fatiguing exercise protocol to ensure a similar level of fatigue leading into the performance trial.
- Comparing Thermoneutral Water Immersion, Cold Water Immersion, Contrast Water Therapy and a control condition, to determine the most effective form of water immersion for performance recovery.
- Comparing active recovery in water with active recovery on land and a control condition, to determine if active recovery in water is more beneficial than the way in which active recovery is currently performed.
- Continuing to explore the use of Humidification Therapy and Electromyostimulation in differing cycling events with highly-trained cyclists.
- The exploration of a combination of multiple recovery strategies and whether the impact on recovery and subsequent performance is greater than using only one strategy.

- The examination of Intermittent Sequential Pneumatic Compression (ISPC) during an actual Omnium event in highly-trained athletes.
- Evaluating the varying brands and modes of Intermittent Sequential Pneumatic Compression.
- Examining the effects of Intermittent Sequential Pneumatic Compression between days during road cycling tours.

References

1. Jeukendrup, A, Craig, N, Hawley, J. The bioenergetics of world class cycling. *J Sci Med Sport.* 2000;3(4): 414-433.

2. Edwards, B, Corte, U. Commercialization and lifestyle sport: lessons from 20 years of freestyle bmx in 'pro-town, USA'. *Sport Soc.* 2010;13(7-8): 1135-1151.

3. Marquet, A-L, Hausswirth, C, Hays, A, Vettoretti, F, Brisswalter, J. Comparison of between-training-sessions recovery strategies for world-class bmx pilots. *Int J Sports Physiol Perform.* 2015;10(2): 219-223.

4. Versey, N, Halson, S, Dawson, B. Effect of contrast water therapy duration on recovery of cycling performance: a dose–response study. *Eur J Appl Physiol.* 2011;111(1): 37-46.

5. Schneider, AJ. Cultural nuances: doping, cycling and the Tour de France. *Sport Soc.* 2006;9(2): 212-226.

6. Ménétrier, A, Pinot, J, Mourot, L, Grappe, F, Bouhaddi, M, Regnard, J, Tordi, N. Effects of recovery using contrast water therapy or compression stockings on subsequent 5-min cycling performance. *J Sci Cycling.* 2013;2(2): 49-56.

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

8. Argus, C, Driller, M, Ebert, T, Martin, D, Halson, S. The effects of 4 different recovery strategies on repeat sprint-cycling performance. *Int J Sports Physiol Perform.* 2013;8(5): 542-548.

9. Stanley, J, Peake, J, Buchheit, M. Consecutive days of cold water immersion: effects on cycling performance and heart rate variability. *Eur J Appl Physiol.* 2013;113(2): 371-384.

10. Craig, N, Norton, K. Characteristics of track cycling. *Sports Med.* 2001;31(7): 457-468.

11. Black, M, Jones, A, Blackwell, J, Bailey, S, Wylie, L, McDonagh, S, Thompson, C, Kelly, J, Sumners, P, Mileva, K. Muscle metabolic and neuromuscular determinants of fatigue during cycling in different exercise intensity domains. *J Appl Physiol.* 2017;122(3): 446-459.

12. Kenney, W, Wilmore, J, Costill, D. *Physiology of Sport and Exercise 6th Edition.* Champaign, IL: Human Kinetics.

13. Cramer, J. *Bioenergetics of exercise and training.* Champaign, IL: Human Kinetics.

14. Gardner, S, Martin, D, Jenkins, D, Dyer, I, Van Eiden, J, Barras, M, Martin, J. Velocity-specific fatigue: quantifying fatigue during variable velocity cycling. *Med Sci Sports Exerc.* 2009;41(4): 904-911.

15. Temesi, J, Mattioni-Maturana, F, Peyrard, A, Piucco, T, Murias, J, Millet, G. The relationship between oxygen uptake kinetics and neuromuscular fatigue in high-intensity cycling exercise. *Eur J Appl Physiol.* 2017;117(5): 969-978.

16. Phillips, S. *Fatigue in sport and exercise.* New York, NY: Routledge.

17. Cairns, S. Lactic acid and exercise performance. *Sports Med.* 2006;36(4): 279-291.

18. Robergs, R, Ghiasvand, F, Parker, D. Biochemistry of exercise-induced metabolic acidosis. *Am J Physiol Regul Integr Comp Physiol.* 2004;287(3): R502-R516.

19. Westerblad, H, Allen, D, Lännergren, J. Muscle fatigue: lactic acid or inorganic phosphate the major cause? *Am Physiol Soc.* 2002;17(1): 17-21.

20. Degroot, M, Massie, B, Boska, M, Gober, J, Miller, R, Weiner, M. Dissociation of [H+] from fatigue in human muscle detected by high time resolution 31P-NMR. *Muscle Nerve.* 1993;16(1): 91-98.

21. Abbiss, C, Laursen, P. Models to explain fatigue during prolonged endurance cycling. *Sports Med.* 2005;35(10): 865-898.

22. Jones, A, Vanhatalo, A, Burnley, M, Morton, R, Poole, D. Critical power: implications for determination of VO_{2max} and exercise tolerance. *Med Sci Sports Exerc.* 2010;42(10): 1876-1890.

23. Allen, D, Lamb, G, Westerblad, H. Skeletal muscle fatigue: cellular mechanisms. *Physiol Rev.* 2008;88(1): 287-332.

24. Millet, G, Lepers, R. Alterations of neuromuscular function after prolonged running, cycling and skiing exercises. *Sports Med.* 2004;34(2): 105-116.

25. Mena, P, Maynar, M, Campillo, J. Changes in plasma enzyme activities in professional racing cyclists. *Brit J Sport Med.* 1996;30(2): 122-124.

26. Chatard, J, Atlaoui, D, Farjanel, J, Louisy, F, Rastel, D, Guézennec, C. Elastic stockings, performance and leg pain recovery in 63-year-old sportsmen. *Eur J Appl Physiol.* 2004;93(3): 347-352.

27. Driller, M, Halson, S. The effects of lower-body compression garments on recovery between exercise bouts in highly-trained cyclists. *J Sci Cycling.* 2013;2(1): 45-50.

28. Brophy-Williams, N, Driller, M, Halson, S, Fell, J, Shing, C. Evaluating the kikuhime pressure monitor for use with sports compression clothing. *Sports Eng.* 2014;17(1): 55-60.

29. Brophy-Williams, N, Driller, M, Kitic, C, Fell, J, Halson, S. Effect of compression socks worn between repeated maximal running bouts. *Int J Sports Physiol Perform.* 2016;12(5): 1-22.

30. Peiffer, J, Abbiss, C, Watson, G, Nosaka, K, Laursen, P. Effect of a 5-min cold-water immersion recovery on exercise performance in the heat. *Brit J Sport Med.* 2008;44(6): 461-465.

31. Vaile, J, Halson, S, Gill, N, Dawson, B. Effect of cold water immersion on repeat cycling performance and thermoregulation in the heat. *J Sport Sci.* 2008;26(5): 431-440.

32. Vaile, J, O'Hagan, C, Stefanovic, B, Walker, M, Gill, N, Askew, C. Effect of cold water immersion on repeated cycling performance and limb blood flow. *Brit J Sport Med.* 2011;45(10): 825-829.

33. Peiffer, J, Abbiss, C, Watson, G, Nosaka, K, Laursen, P. Effect of cold-water immersion duration on body temperature and muscle function. *J Sport Sci.* 2009;27(10): 987-993.

34. Vaile, J, Halson, S, Gill, N, Dawson, B. Effect of hydrotherapy on recovery from fatigue. *Int J Sports Med.* 2008;29(7): 539-544.

35. Peiffer, J, Abbiss, C, Watson, G, Nosaka, K, Laursen, P. Effect of cold water immersion on repeated 1-km cycling performance in the heat. *J Sci Med Sport.* 2008;13(1): 112-116.

36. Buchheit, M, Peiffer, J, Abbiss, C, Laursen, P. Effect of cold water immersion on postexercise parasympathetic reactivation. *Am J Physiol Heart Circ Physiol.* 2009;296(2): H421-H427.

37. Christensen, P, Bangsbo, J. Influence of prior intense exercise and cold water immersion in recovery for performance and physiological response during subsequent exercise. *Front Physiol.* 2016;7(269): 1-10.

38. Stanley, J, Buchheit, M, Peake, J. The effect of post-exercise hydrotherapy on subsequent exercise performance and heart rate variability. *Eur J Appl Physiol.* 2012;112(3): 951-961.

39. Chan, Y-Y, Yim, Y-M, Bercades, D, Cheng, TT, Ngo, K-L, Lo, K-K. Comparison of different cryotherapy recovery methods in elite junior cyclists. *Asia Pac J Sports Med Arthrosc Rehabil Technol.* 2016;5(1): 17-23.

40. Schniepp, J, Campbell, T, Powell, K, Pincivero, D. The effects of cold-water immersion on power output and heart rate in elite cyclists. *J Strength Cond Res.* 2002;16(4): 561-566.

41. Peiffer, J, Abbiss, C, Nosaka, K, Peake, J, Laursen, P. Effect of cold water immersion after exercise in the heat on muscle function, body temperatures, and vessel diameter. *J Sci Med Sport.* 2007;12(1): 91-96.

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

43. Lit, K, Chen, C, Ang, B. Effects of acute cool water immersion on time trial performance and exercised-induced oxidative stress among endurance cyclists in the heat. *J Athl Enhancement* 2014;3(4): 1-5.

44. Babault, N, Cometti, C, Maffiuletti, N, Deley, G. Does electrical stimulation enhance post-exercise performance recovery? *Eur J Appl Physiol.* 2011;111(10): 2501-2507.

45. Hasani, A, Chapman, T, McCool, D, Smith, R, Dilworth, J, Agnew, J. Domiciliary humidification improves lung mucociliary clearance in patients with bronchiectasis. *Chron Respir Dis.* 2008;5(2): 81-86.

46. Bielik, V. Effect of different recovery modalities on anaerobic power in off-road cyclists. *Biol Sport.* 2010;27(1): 59-63.

47. Martin, N, Zoeller, R, Robertson, R, Lephart, S. The comparative effects of sports massage, active recovery, and rest in promoting blood lactate clearance after supramaximal leg exercise. *J Athl Train.* 1998;33(1): 30-35.

48. Paoli, A, Bianco, A, Battaglia, G, Bellafiore, M, Grainer, A, Marcolin, G, Cardoso, CC, Dall'Aglio, R, Palma, A. Sports massage with ozonised oil or non-ozonised oil: comparative effects on recovery parameters after maximal effort in cyclists. *Physical Therapy in Sport.* 2013;14(4): 240-245.

49. Monedero, J, Donne, B. Effect of recovery interventions on lactate removal and subsequent performance. *Int J Sports Med.* 2000;21(08): 593-597.

50. Kingsley, D, Zakrajsek, R, Nesser, T, Gage, M. The effect of motor imagery and static stretching on anaerobic performance in trained cyclists. *J Strength Cond Res.* 2013;27(1): 265-269.

51. Samuel, M, Holcomb, W, Guadagnoli, M, Rubley, M, Wallmann, H. Acute effects of static and ballistic stretching on measures of strength and power. *J Strength Cond Res.* 2008;22(5): 1422-1428.

52. Costa, P, Ryan, E, Herda, T, Walter, A, DeFreitas, J, Stout, J, Cramer, J. Acute effects of static stretching on peak torque and the hamstrings-to-quadriceps conventional and functional ratios. *Scand J Med Sci Spor.* 2013;23(1): 38-45.

53. Asplund, C, St Pierre, P. Knee pain and bicycling: fitting concepts for clinicians. *Phys Sportsmed.* 2004;32(4): 23-30.

54. Connolly, D, Brennan, K, Lauzon, C. Effects of active versus passive recovery on power output during repeated bouts of short term, high intensity exercise. *J Sports Sci Med.* 2003;2(2): 47-51.

55. Ferreira, J, Da Silva Carvalho, R, Barroso, T, Szmuchrowski, L, Śledziewski, D. Effect of different types of recovery on blood lactate removal after maximum exercise. *Pol J Sport Tourism.* 2011;18(2): 105-111.

56. Zelikovski, A, Kaye, C, Fink, G, Spitzer, S, Shapiro, Y. The effects of the modified intermittent sequential pneumatic device (MISPD) on exercise performance following an exhaustive exercise bout. *Brit J Sport Med.* 1993;27(4): 255-259.

57. Hanson, E, Stetter, K, Li, R, Thomas, A. An intermittent pneumatic compression device reduces blood lactate concentrations more effectively than passive recovery after wingate testing. *J Athl Enhanc.* 2013;2(3): 18-25.

58. Ofoghi, B, Zeleznikow, J, MacMahon, C, Dwyer, D. A machine learning approach to predicting winning patterns in track cycling omnium. In: *Artificial Intelligence in Theory and Practice III.* 2010:67-76.

59. Bentley, D, McNaughton, L, Thompson, D, Vleck, V, Batterham, A. Peak power output, the lactate threshold, and time trial performance in cyclists. *Med Sci Sports Exerc.* 2001;33(12): 2077-2081.

60. Bishop, D, Bonetti, D, Dawson, B. The effect of three different warm-up intensities on kayak ergometer performance. *Med Sci Sports Exerc.* 2001;33(6): 1026-1032.

61. Borne, R, Hausswirth, C, Bieuzen, F. Relationship between blood flow and performance recovery: a randomized, placebo-controlled study. *Int J Sports Physiol Perform.* 2016;12(2): 152-160.

62. O'Donnell, S, Driller, M. The effect of intermittent sequential pneumatic compression on recovery between exercise bouts in well-trained triathletes. *J Sci Cycling.* 2015;4(3): 19.

63. Chleboun, G, Howell, J, Baker, H, Ballard, T, Graham, J, Hallman, H, Perkins, L, Schauss, J, Conatser, R. Intermittent pneumatic compression effect on eccentric exercise-induced swelling, stiffness, and strength loss. *Arch Phys Med Rehabil.* 1995;76(8): 744-749.

64. Hill, J, Howatson, G, van Someren, K, Davidson, S, Pedlar, C. The variation in pressures exerted by commercially available compression garments. *Sports Eng.* 2015;18(2): 115-121.

65. Chen, A, Frangos, S, Kilaru, S, Sumpio, B. Intermittent pneumatic compression devices – physiological mechanisms of action. *Eur J Vasc Endovasc Surg.* 2001;21(5): 383-392.

66. Northey, J, Rattray, B, Argus, C, Etxebarria, N, Driller, M. Vascular occlusion and sequential compression for recovery after resistance exercise. *J Strength Cond Res.* 2016;30(2): 533-539.

67. Wiener, A, Mizrahi, J, Verbitsky, O. Enhancement of tibialis anterior recovery by intermittent sequential pneumatic compression of the legs. *Basic Appl Myol.* 2001;11(2): 87-90.

68. Phillips, K, Hopkins, W. Performance relationships in timed and mass-start events for elite omnium cyclists. *Int J Sports Physiol Perform.* 2016;12(5): 628-633.

69. Hopker, J, Myers, S, Jobson, S, Bruce, W, Passfield, L. Validity and reliability of the Wattbike cycle ergometer. *Int J Sports Med.* 2010;10(31): 731-736.

70. Vanhatalo, A, Doust, J, Burnley, M. Determination of critical power using a 3-min all-out cycling test. *Med Sci Sports Exerc.* 2007;39(3): 548.

71. Kraemer, W, Bush, J, Wickham, R, Denegar, C, Gómez, A, Gotshalk, L, Duncan, N, Volek, J, Putukian, M, Sebastianelli, W. Influence of compression therapy on symptoms following soft tissue injury from maximal eccentric exercise. *J Orthop Sport Phys.* 2001;31(6): 282-290.

72. Borg, G. *Borg's Perceived exertion and pain scales.* Champaign, IL: Human Kinetics.

73. Miller, F, Manfredi, T. Physiological and anthropometrical predictors of 15-kilometer time trial cycling performance time. *Res Q Exercise Sport.* 1987;58(3): 250-254.

74. Bonaventura, J, Sharpe, K, Knight, E, Fuller, K, Tanner, R, Gore, C. Reliability and accuracy of six hand-held blood lactate analysers. *J Sports Sci Med.* 2015;14(1): 203.

75. Driller, M, Argus, C, Bartram, J, Bonaventura, J, Martin, D, West, N, Halson, S. Reliability of a 2-bout exercise test on a Wattbike cycle ergometer. *Int J Sports Physiol Perform.* 2014;9(2): 340-345.

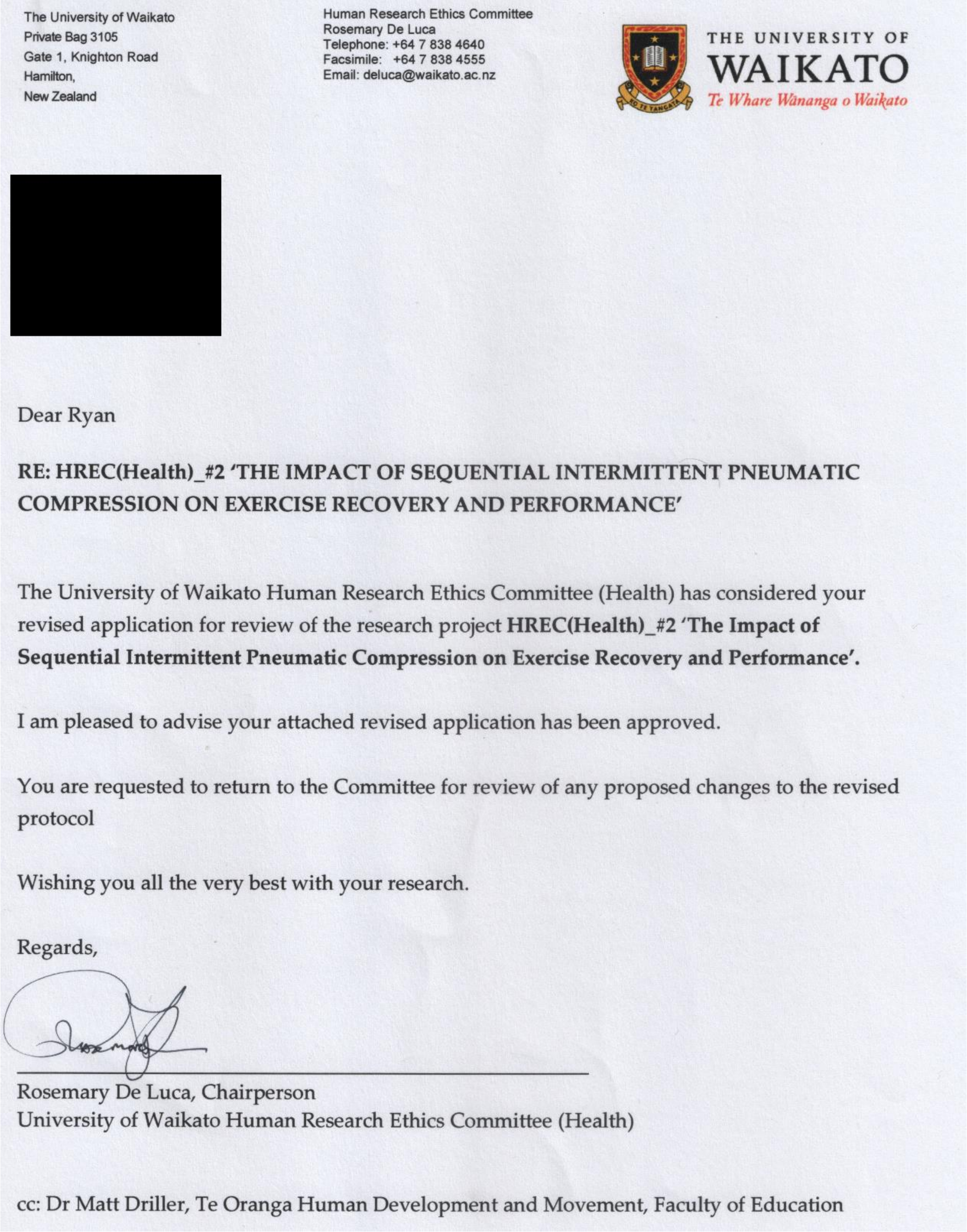
76. Cohen, J. *Statistical power analysis for the behavioral sciences.* Hillsdale, N.J: L. Erlbaum Associates.

77. Batterham, A, Hopkins, W. Making meaningful inferences about magnitudes. *Int J Sports Physiol Perform.* 2006;1(1): 50-57.

Appendices

Appendix One:

Ethics Approval



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THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

[redacted]

Dear Ryan

RE: HREC(Health)_#2 'THE IMPACT OF SEQUENTIAL INTERMITTENT PNEUMATIC COMPRESSION ON EXERCISE RECOVERY AND PERFORMANCE'

The University of Waikato Human Research Ethics Committee (Health) has considered your revised application for review of the research project **HREC(Health)_#2 'The Impact of Sequential Intermittent Pneumatic Compression on Exercise Recovery and Performance'.**

I am pleased to advise your attached revised application has been approved.

You are requested to return to the Committee for review of any proposed changes to the revised protocol

Wishing you all the very best with your research.

Regards,

Rosemary De Luca, Chairperson
University of Waikato Human Research Ethics Committee (Health)

cc: Dr Matt Driller, Te Oranga Human Development and Movement, Faculty of Education

Appendix Two:

Participant Information

Dear Participant,

You are being invited to take part in a research study, which will help determine the effect of Intermittent Sequential Pneumatic Compression (Recovery Boots) on exercise recovery and subsequent performance. Before you volunteer to take part in this study, it is important that you understand what it will involve. Please take the time to read the following information carefully and if there is anything that is not clear or you would like more information, please feel free to contact us.

Purpose

The aim of this study is to determine the impact of Recovery Boots on exercise recovery and subsequent performance in well-trained cyclists.

Significance

Recovery from training and competition is a fundamental aspect of athlete regimen. Incorporating appropriate recovery is believed to enhance training and competition quality and quantity. Intermittent sequential pneumatic compression is a technique used in the medical setting to treat patients with venous insufficiencies. More recently, this technique has been adapted to the sport setting to enhance athletic recovery. However, its claims are largely anecdotal and research is necessary to determine its efficacy.

Recovery Boots (RecoveryPump, TX, USA) are a commercially available product that utilises intermittent sequential pneumatic compression to assist in recovery from exercise. The boot encloses the leg, from the foot to the upper thigh. Four compartments inflate sequentially at pressures of ~80mmHg.

To date, no study has examined the impact of Recovery Boots on recovery and subsequent performance in well-trained cyclists.

Selection Criteria

Healthy male and/or female cyclists with no contraindications to vigorous exercise and who meet the following criteria will be selected.

To be eligible in this study you must be:

- Available to attend the University of Waikato Sport Science Lab in the Avantidrome, Cambridge, New Zealand on two separate occasions. Each visit will last approximately 80-mins.
- Aged between 18 and 50 years.
- Undertaking three or more training sessions for cycling per week (30-mins or longer).
- Have competed in a track race over the past 6 months.

And NOT have the following:

- Injury, illness or health issues which would disrupt performance e.g. lower limb injury ● Injury, illness or health issues which would endanger your health e.g. heart condition

If you meet all of the aforementioned criteria then you can choose to participate in this research project.

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time without reason. You may choose to withdraw your results up until the point of analysis (after your last lab test).

Protocol

Participants will be required to attend the University of Waikato Sport Science Lab at the Avantidrome in Cambridge, NZ for three consecutive weeks.

The first week will be a familiarisation trial where you get a feel for the study and the following two weeks will be experimental trials.

The outline of the testing session is highlighted in the table below:

Testing Protocol

Warm-up One: 5-min cycling on Wattbike
Bout One: 20-min cycling on Wattbike
Recovery: 30-mins. Recovery Boots (experimental) / passive seated (control)
Warm Up Two: 5-min cycling on Wattbike
Bout 2: 4-min max effort on Wattbike

Blood Lactate Testing: A finger-prick blood sample will be taken at the beginning and end of the recovery period to analyse blood lactate levels.

During your familiarisation trial, a metabolic cart will be used to analyse VO_{2max} during your 4-min effort.

Recovery Interventions

In a randomised crossover design, participants will perform one of two conditions immediately following the cycling bout: Passive recovery or Recovery Boots.

Recovery Boots

Participants will be seated with Recovery Boots fitted to both legs and operated as per the manufacturer’s recommendations (80mmHg) for 30mins.

Passive Recovery

Participants will be seated for 30-mins. This condition will act as the control.

What you will gain from participating in the study?

As a participant, you will benefit from experience with the research process and gain knowledge about the area of research. You will be involved in innovative research, which will provide valuable information on recovery for cyclists. We will also identify for you the following which will assist your Cycling Coach and/or Strength and Conditioning Specialist:

1) 20-min average power
2) 4-min average power
3) Blood lactate concentration post 20-min cycling effort and post 30-min recovery protocol
4) VO_{2max} (indication of fitness level)

All information collected about you during the course of the research project will be kept strictly confidential. You will be identified by a code number and all personal information will be kept private. This will be in accordance with the 1993 Privacy Act.

This research study has been approved by the University of Waikato Human Research Ethics Committee (health).
Official study number: **HREC_Health#2**

Please contact us should you have any cultural concerns with regards to collecting/storing/disposing of blood and/or if you would like a cultural advisor involved.

Any inquiries regarding requirements and procedures used in this study are encouraged. Please contact us if you have any questions. Contact details over the page.

Contact Details for Researcher and Supervisor

Ryan Overmayer
Principal Researcher
The University of Waikato
Mobile: [redacted]
E-mail: [redacted]

Dr. Matt Driller
Principal Supervisor
The University of Waikato
E-mail: [redacted]

Appendix Three:

Research Informed Consent Form

Informed Consent form

Project Title: The Impact of Intermittent Sequential Pneumatic Compression on Exercise Recovery and Subsequent Performance

Principal Researcher: Ryan Overmayer
Principal Supervisor: Dr. Matt Driller

This is to certify that I   hereby agree to participate as a volunteer in a scientific investigation as an authorised part of the research program of the University of Waikato under the supervision of Ryan Overmayer.

The investigation and my part in the investigation have been defined and fully explained to me by Ryan Overmayer and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts have been provided to me and discussed in detail with me.

- I have been given an opportunity to ask whatever questions I may have had and all questions have been answered to my satisfaction.
- I understand that I am free to withdraw consent and to discontinue participation in the project or activity at any time, without disadvantage to myself.
- I understand that I am free to withdraw my data up until the point of analysis (after the last lab test) without disadvantage to myself.
- I understand that any data will remain anonymous with regard to my identity through a coding system. The data will be made publishable, so every effort will be made to ensure confidentiality, however this cannot be guaranteed.
- I certify to the best of my knowledge and belief, I have no physical or mental illness or weakness that would increase my risk to participate in this investigation.
- I am participating in this project of my own volition and I have not been coerced in any way to participate.

- I have been asked and affirm that I have no concerns with Tikanga/Maori protocol/customs in regards to collecting/storing/disposing of blood.

- I have been given the opportunity to involve a cultural advisor and affirm that I feel culturally safe.

Signature of Subject: ____

Date: ____/____/____

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: ____________________________________
Date:___/____/___

Contact Details for Researcher and Supervisor

Ryan Overmayer
Principal Researcher
The University of Waikato
Mobile: [redacted]
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Appendix Four:

Pre-test Medical Questionnaire

THE UNIVERSITY OF
WAIKATO
Te Whare Wānanga o Waikato

First Name/s______________________________ Surname____________________

Date of Birth_____/______/_____

Gender (circle) Male Female

Please answer the following questions by circling the appropriate response, or filling in the blank.

1. How would you describe your present level of activity?
   Sedentary Moderately Active Active Highly Active

2. How would you describe your present level of fitness?
   Unfit Moderately Fit Trained Highly Trained

3. How would you consider your present body weight?
   Underweight Ideal Slightly Over Very Overweight

4. Smoking habits:

Are you currently a smoker? **Yes** **No**

How many do you smoke? ……per day

Are you a previous smoker? **Yes** **No**

How long is it since you stopped? ……..years

Were you an occasional smoker? **Yes** **No**

……per day

Were you a regular smoker? **Yes** **No**

……per day

5. **Do you drink alcohol?** **Yes** **No**
If you answered **Yes**, do you have?

An occasional drink A drink everyday More than one drink a day

6. **Have you had to consult your doctor in the previous six months?** **Yes** **No**
If you have answered **YES,** please provide details:

…………………………………………………………………………………………………

………………………………………………………………………………………………

7. **Are you presently taking any form of medication?** **Yes** **No**
If you have answered **YES,** please provide details:

…………………………………………………………………………………………………

………………………………………………………………………………………………

8. **As far as you are aware, do you suffer from or have you ever suffered from?(circle if yes to any)**

a. Diabetes	b. Asthma
c. Epilepsy	d. Bronchitis
d. Any form of heart complaint*	e. Raynaud's Disease
f. Marfans Syndrome*	h. Aneurysm/embolism*
i. Anaemia	j. Haemophilia*

9. ***Is there a history of heart disease in your family?**

Yes **No**

10. ***Do you currently have any form of muscle or joint injury?**

Yes **No**

11. **Have you had to suspend your normal training in the previous two weeks?**

Yes **No**

12. **Please read and answer the following questions:**

a. Are you suffering from any known serious infections?

Yes **No**

b. Have you had jaundice within the previous year?

Yes **No**

c. Have you ever had any form of hepatitis?

Yes **No**

d. Are you HIV antibody positive?
Yes **No**

e. Have you ever been involved in intravenous drug use?
Yes **No**

f. For females, are you currently, or in the previous 6 months, pregnant? **Yes** **No**

13. As far as you are aware, is there anything that might prevent you from successfully completing the tests that have been outlined to you?

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

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

If the answer to any of the above questions is yes then:

a. Discuss with the clinic personal the nature of the issue

Consent of Athlete/Participant

__________________________	____/_____/____
Athlete/Participant Signature	Date

__________________________	________________________	____/_____/___
Guardian name (if age less than 16 yrs)	Athlete/Participant Signature	Date
__________________________	________________________	____/_____/___
Witness name	Signature	Date

Appendix Five:

Rating of Perceived Exertion Scale

6	**No Exertion at All**
7	**Extremely Light**
8	
9	**Very Light**
10	
11	**Light**
12	
13	**Somewhat Hard**
14	
15	**Hard (Heavy)**
16	
17	**Very Hard**
18	
19	**Extremely Hard**
20	**Maximal Exertion**

Borg, G.A., (1982). Physiological basis of physical exertion. *Medicine and Science in Sport and Exercise*, 14, p 377.

Appendix Six:

'Belief' Scale

Do you believe Recovery Boots will aid your recovery?
(Mark using a vertical line on the line below)

____

Absolutely Not	Unsure	Absolutely Yes

Measurement: ______________mm

Appendix Seven:

The Effects of Tissue Flossing on Ankle Range of Motion and Jump Performance

Abstract

Objectives: Tissue compression and partial vascular occlusion using band flossing results in re-perfusion of blood to the muscle tissue that may ultimately increase range of motion (ROM) and reduce risk of injury. However, the effect of band flossing on ankle ROM and jump performance is yet to be evaluated. **Design**: In a crossover design, participants performed a number of tests pre and post the application of a floss band to one ankle (FLOSS), with the contralateral ankle acting as the control (CON).
Setting: University laboratory. **Participants:** 52 recreational athletes (29 male/ 23 female). **Main outcome measures:** Pre and post measures included a weight-bearing lunge test (WLBT), ankle dorsiflexion (DF) and plantarflexion (PF) ROM, and single leg vertical jump height and velocity. **Results**: FLOSS resulted in significant enhancements in all test measures pre to post ($p<0.01$), with no significant changes pre to post for CON ($p>0.05$). All pre to post changes were associated with *small* effect sizes for FLOSS compared to CON. **Conclusion**: Floss bands applied to the ankle increase dorsiflexion and plantarflexion ROM and improve single-leg jump performance in recreational athletes. The results from this study suggest that floss bands may be used for injury prevention and athletic performance.

Keywords*:* *flossbands, mobility bands, vascular occlusion, ischemic pre-conditioning, ROM.*

Introduction

The anecdotal use of floss/mobility bands, or “tissue flossing”, amongst athletes is becoming a popular strategy to increase joint range of motion (ROM), enhance prevention or rehabilitation from injury and improve athletic performance, despite limited evidence for its efficacy. Tissue flossing involves the wrapping of a thick rubber band around a joint or muscle, partially occluding blood-flow while often concomitantly performing ROM tasks for 1-3 minutes. This technique gained popularity through the book by Starrett and Cordoza (2013), where the authors introduced floss band compression for increasing ROM and postulated that the potential mechanisms behind the benefit of using floss bands may be attributed to fascial shearing and/or reperfusion of blood to the muscle.

While the research studies regarding tissue flossing are currently lacking, the mechanisms involved may be similar to that of ischemic preconditioning/blood-flow occlusion/restriction training, whereby reperfusion of blood to the occluded area, enhanced growth hormone and catecholamine responses are suggested to improve exercise performance (Reeves et al., 2006; Takarada et al., 2000). Furthermore, in animal models, ischemic preconditioning has been shown to improve muscle contraction efficiency, possibly by enhancing muscle force and contractility (Lawson & Downey, 1993) and/or via increased efficiency of excitation-contraction coupling (Pang et al., 1995).

To the authors knowledge, the extent of research examining the effect of tissue flossing in an athletic setting is limited to two studies, published as conference proceedings (Bohlen et al., 2014; Plocker, Wahlquist, & Dittrich, 2015). Bohlen et al., (2014) examined the effects of 14 days of band flossing combined with joint mobilization and resistive exercise on calf blood flow and plantar/dorsiflexion strength in five participants. Participants performed unloaded squats, heel raises, active dorsiflexion and passive ankle mobilization with floss bands applied to one knee while the contralateral leg acted as the control. Dorsiflexion peak torque increased 22% in the treatment leg (p=0.06), while there was no change in the control leg. The authors also reported no change in blood-flow parameters between legs following the 14-day study.

In contrast, Plocker et al., (2015) studied the effect of applying floss bands to both shoulders in 17 male athletes in an acute setting. Subjects attended an experimental session whereby the researchers wrapped both shoulders with a floss band, and led subjects through shoulder ROM exercises. Upon band removal, ROM measurements (internal and external rotation) were taken using a goniometer. A 3D accelerometer was then used to measure upper extremity power during the bench press. The control session involved the same shoulder exercises without the use of the floss band modality. The study reported that despite trends towards improvements, there were no significant increases in ROM or upper-body power (p>0.05) following the floss band treatment when compared to the control. Researchers concluded that it was difficult to cover the entire shoulder (rotator cuff complex) with the wrapping technique, potentially limiting the effectiveness of improving shoulder ROM. Other joints, such as the ankle, may be easier to cover using the floss band wrapping technique.

Ankle dorsiflexion ROM is an important component in the absorption of lower limb load when landing from a jump, as common in most sports (Malliaras, Cook, & Kent, 2006). When landing from a jump, the forefoot usually contacts the ground and then the ankle moves into dorsiflexion. Indeed, it has been suggested that reduced ankle dorsiflexion range may be a risk factor for the development of patellar tendinopathy and is also a risk factor for anterior cruciate ligament (ACL) injury and other lower-limb injuries in athletes (Fong, Blackburn, Norcross, McGrath, & Padua, 2011; Gabbe, Finch, Wajswelner, & Bennell, 2004; Malliaras et al., 2006). Moreover, restricted dorsiflexion has been implicated as a contributing factor in overuse injuries of the lower limb and foot (Warren & Jones, 1987).

Given the relatively novel technique of tissue flossing has only been examined in two studies, with contrasting results, the modality requires further research. Furthermore, it is well known that improvements in ankle ROM may lead to enhanced performance in many sport, exercise and rehabilitation settings (Conradsson, Fridén, Nilsson-Wikmar,

& Ang, 2010; Larson, 2014; Malliaras et al., 2006; Tabrizi, McIntyre, Quesnel, & Howard, 2000), making it an obvious area for investigation. Therefore, the aim of the current study was to evaluate the use of floss bands applied to the ankle joint, on subsequent ankle ROM and jump height in recreational athletes.

Methods

Participants

Fifty-two recreational athletes (29 male/ 23 female, mean ± SD; age: 20 ± 4 years) volunteered to participate in the current study. Participants were recruited through a University sport science under-graduate program. To be eligible for the study, all participants were required to be participating in regular physical exercise sessions (>3 times per week) and free from lower-limb injuries (hip, knee or ankle) that may have affected their ability to perform the single-leg jumps. Written informed consent was obtained from each participant, and ethical approval was obtained from the Human Research Ethics Committee of the institution.

Experimental Design

Participants performed a number of lower-leg tests pre and post application of a floss band (FLOSS) or no floss band (CON) to the ankle-region. For each participant, the ankle that had no floss band served as the control for pre and post testing, while the ankle with the floss band served as the experimental treatment. Participants attended a sport science laboratory for a single testing session. Following the pre tests, in a randomised (computerised random number generator), counterbalanced design, researchers applied a floss band (Life Flossbands, Sydney, Australia), to either the right (n = 26) or left (n = 26) ankle of participants. Post tests were then performed in the same order as the pre tests. The order of tests for all participants were as follows: the weight bearing lunge test, plantarflexion ROM, dorsiflexion ROM and single leg vertical jump test.

Figure 1 – The floss band ankle bandaging technique used by researchers

Methodology

Weight-bearing lunge test (WBLT)

The WBLT was performed pre and post flossing as a measure of dorsiflexion range of motion. Participants placed their foot along a measuring tape on the floor, with their big toe against the wall and both their toe and heel on the centerline of the measuring tape.

Participants were then asked to progressively move their toe further back from the wall on the measuring tape, repeating the lunge movement until the maximum distance at which they could tolerably lunge their knee to the wall without heel lift was found. Measurement was made using the tape measure from the tip of their big toe to the wall. The weight-bearing lunge test (WBLT) is a functional and reliable method to indirectly assess dorsiflexion by measuring the maximal advancement of the tibia over the rearfoot in a weight-bearing position (Bennell et al., 1998). Previous investigators have reported robust inter-tester and intra-tester reliability associated with the assessment of WBLT performance in healthy adults, with high levels of test-retest reliability demonstrated (standard error of measurement = 1.1°, 95% CI = 2.2) (Bennell et al., 1998).

Dorsiflexion and Plantarflexion ROM

Both dorsiflexion (DF) and plantarflexion (PF) range of motion tests were performed using a handheld manual goniometer (RBMS®, USA) pre and post flossing. Tests were performed while participants were in a supine position. The center of the goniometer was placed just below the lateral malleolus of the ankle, with one arm lined up through the lateral aspect of the fibula and the other arm lined up with the 5th metatarsophalangeal joint. Participants were instructed to perform a maximal dorsiflexion movement and a maximal plantarflexion movement and measurements (degrees) were taken for analysis. Acceptable intra-tester reliability for assessing ankle ROM using a manual goniometer has been reported previously (ICC = ~0.85) (Youdas, Bogard, & Suman, 1993).

Single-leg vertical jump test (JUMP)

Data regarding the maximal jump height ($JUMP^H$) and the peak jump velocity ($JUMP^V$) were measured using a linear position transducer (Gymaware, Kinetic Athlete, Canberra, Australia) pre and post flossing. The Gymaware device was calibrated before each jump, according to manufacturer's instructions. $JUMP^H$ was measured in metres, while $JUMP^V$ was measured in $m.s^{-1}$. Single-leg countermovement jumps were performed and the best of three attempts for each leg was recorded and used for subsequent analysis. High levels of validity (typical error of estimate of 0.00m for jump height and 0.01m/s for peak and mean velocity) for the Gymaware device have been reported elsewhere (Hori & Andrews, 2009).

Kikuhime pressure measurement

In a selection of participants (n = 12), interface pressure between the skin and the floss band was measured to assess the level of compression (mmHg) achieved by the wrapping technique. The Kikuhime pressure monitor (MediGroup, Melbourne, Australia) sensor was placed on the anterior aspect of the tibia on the midline between the lateral and medial malleolus (Figure 2). The Kikuhime pressure monitor has been shown to be a valid (ICC = 0.99, CV = 1.1%) and reliable (CV = 4.9%) tool for use in the sport setting (Brophy-Williams, Driller, Halson, Fell, & Shing, 2014).

Figure 2 – The Kikuhime pressure monitoring device applied under the floss band.

Application of floss band

A standard ankle-bandaging technique was used by researchers by applying the floss band accordingly: Across the transverse of the foot, aligned with the distal head of the metatarsals of the foot. The wrap circulated around the foot twice, followed by 3 wraps completed in a figure 8 (to lateral malleolus, around the achilles, to medial malleolus, towards the distal head of the 5th metatarsal, around the bottom of the foot and back to the beginning). Each subsequent wrap overlapped the previous by ~50%, before securing the remainder of the band underneath the final wrap (Figure 1). Once the floss band was applied, in a seated position, participants performed an active ROM task - 20 repetitions of plantarflexion and dorsiflexion, simultaneously on both the CON and FLOSS ankles. Participants were instructed to perform both plantarflexion and dorsiflexion to their extreme ranges of motion and completed the mobility exercises within two minutes. After two minutes, the floss band was then removed and the participants were instructed to stand up and walk around for one minute to allow for blood flow to return to the foot.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL). A two-way repeated measures ANOVA was performed to determine the effect of different treatments (FLOSS or CON) over time (pre/post) on all measured variables, with a Bonferroni adjustment if significant main effects were present. Analysis of the studentized residuals was verified visually with histograms and also by the Shapiro-Wilk test of normality. A Student's paired t-test was used to determine pre to post differences for each condition and also between treatments for pre test values. Descriptive statistics are shown as means ± standard deviations unless stated otherwise. Standardized changes in the mean of each measure were used to assess magnitudes of effects and were calculated using Cohen's *d* and interpreted using thresholds of 0.2, 0.5, 0.8 for *small, moderate and large*, respectively (Cohen, 1988). An effect size of ±0.2 was considered the smallest worthwhile effect with an effect size of <0.2 considered to be *trivial*. The effect was deemed *unclear* if its 90% confidence interval overlapped the thresholds for *small* positive and negative effects (Batterham & Hopkins, 2006). Statistical significance was set at $p<0.05$ for all analyses.

Results

Mean pressure (± SD) applied by the floss band in a cohort of the study population (n=12), as identified using the Kikuhime pressure monitor, was 182 ± 38 mmHg. There were no significant differences between FLOSS and CON for any of the measured variables pre test ($p>0.05$). There was a statistically significant interaction between treatment (FLOSS/CON) and time (pre/post) for the WBLT, DF and JUMPv measures ($p<0.01$), but not for PF or JUMP_H ($p>0.05$, Table 1). FLOSS resulted in significant enhancements in all test measures pre to post application of the floss bands (WBLT, PF, DF $JUMP_H$, $JUMP_V$, $p<0.01$), while there were no significant differences pre to post CON ($p>0.05$). All measures were all associated with *small* effects sizes in favour of FLOSS when compared to CON (Table 1).

The WBLT resulted in a 1.8 cm increase pre to post for FLOSS, compared to a 0.2 cm increase in CON. ROM for both PF (+5 degrees) and DF (-7 degrees) were improved in FLOSS, compared to just +2 degrees for PF and -1 degree for DF in CON. Similar increases were observed pre to post for $JUMP_H$ in both FLOSS and CON (0.04 m and 0.02 m, respectively). $JUMP_V$ was further enhanced (pre to post) in FLOSS ($0.15 m.s^{-1}$) when compared to CON ($0.03 m.s^{-1}$).

Table 1 – Pre and post measures (mean ± SD) for floss band (FLOSS) and control (CON) trials and effect sizes for the comparison of change between groups (±90% confidence intervals). $^{\#}$ Represents significant difference between pre and post ($p<0.01$), * Represents significant intervention * time interaction between groups ($p<0.01$).

	FLOSS (mean ± SD)		CON (mean ± SD)		FLOSS - CON Effect size (±90%CI)
	Pre	Post	Pre	Post	
WBLT (cm)	10.9 ± 6.0	12.7 ± 6.5$^{\#}$	11.4 ± 6.7	11.6 ± 6.5	0.29 ±0.09* *small*
PF (degrees)	162 ± 16	167 ± 14$^{\#}$	162 ± 13	164 ± 14	0.22 ±0.19 *small*
DF (degrees)	95 ± 12	88 ± 13$^{\#}$	93 ± 12	92 ± 12	-0.49 ±0.21* *small*
JUMP^{H} (m)	0.23 ± 0.07	0.27 ± 0.08$^{\#}$	0.24 ± 0.07	0.26 ± 0.15	0.28 ±0.32 *small*
JUMP^{V} (m.s^{-1})	1.88 ± 0.35	2.03 ± 0.37$^{\#}$	1.94 ± 0.53	1.97 ± 0.44	0.22 ±0.14* *small*

Discussion

The current study is the first to investigate the use of floss bands applied to the ankle on dorsiflexion and plantarflexion ROM and subsequent vertical jump performance. The findings from our study show significant improvements in all ROM measures as well as single-leg jump performance following the application of a floss band while performing ~2 minutes of active ROM exercises, in a group of 52 recreational athletes ($p<0.01$, Table 1). All results were associated with a *small* effect size in favour of the floss band treatment. The *small* but significant effects found for tissue flossing may provide practical implications for numerous settings including the use of the technique to enhance injury prevention, injury rehabilitation and athletic performance.

While this is the first study to evaluate the effect of floss bands on the ankle joint, our findings are in contrast to the only other previous study evaluating the effect of floss bands on ROM and performance in an acute setting (Plocker et al., 2015). Plocker et al. (2015) did not find any significant improvements in shoulder ROM or upper-body power following the application of floss bands. The only other study, to our knowledge, to evaluate the use of floss bands in an athletic setting, assessed the use of this technique in a chronic (14-day) setting while applying the band to the knee during daily exercises. Similar to the findings in the current study, the authors reported benefits to dorsiflexion measures following the experimental period. The potential improvements to ankle ROM following band flossing may apply to areas other than athletic performance, including their potential as an injury prevention method.

Although the majority of studies investigating ACL injury and landing biomechanics have focused on the knee and hip joints, considerably less attention has been devoted to the ankle. Ankle plantarflexors and dorsiflexors play a substantial role in the absorption of landing forces (Malliaras et al., 2006). Indeed, Fong et al. (2011) has shown that greater passive ankle dorsiflexion ROM was associated with greater knee-flexion displacement and smaller ground reaction forces during landing in 35 active participants. These biomechanical results are considered to lower the risk factors for ACL injury (Griffin et al., 2006; Hewett et al., 2005), therefore Fong et al. (2011)

indicated that any techniques that increase plantarflexor extensibility and dorsiflexion ROM may attenuate ACL injury risk by placing the lower extremity in a position consistent with reduced ACL loading. Given we were able to significantly improve both plantarflexion and dorsiflexion ROM through the use of floss bands in the current study, possibly through the fascial shearing mechanism (Starrett & Cordoza, 2013), this may prove to be an appropriate technique to use in addition to a warm-up before sporting events where jumping is required, in order to decrease the risk of lower-limb injury. Furthermore, results from the current study would suggest that jump performance can be enhanced following the application of floss bands to the ankle joint.

The physiological mechanisms by which performance may be improved following band flossing are difficult to determine, and since these were not measured in the current study, any theories are somewhat speculative. However, the partial vascular occlusion effect that band flossing has on the joints may cause a number of physiological responses following the removal of the band. These responses may include reperfusion of blood to the area and altered hormonal responses (Takano et al., 2005). More specifically, research has shown that following occlusion (~200mmHg) to the upper leg using a tourniquet during resistance exercise, growth hormone and norepinephrine levels significantly increase ~15 minutes after the occlusion is released (Reeves et al., 2006; Takarada et al., 2000). Furthermore, Morales et al, (2014) has suggested that elevated acute norepinephrine are associated with improved vertical jump ability. It is therefore plausible that these same hormonal responses were achieved in the current study with floss bands applied (~182mmHg), potentially contributing to enhanced jump performance ~5 minutes following the removal of the floss bands. Lawson & Downey (1993) suggested that ischemic preconditioning in rat skeletal muscles led to improved force and contractility as well as decreased fatigue. However, the mechanisms behind repeated muscle-contractions are likely to be different to those of one-off jump performance and mechanistic human research is still lacking.

We would recommend that these physiological mechanisms, including the localised blood-flow and hormonal responses following band flossing, are measured in future research studies on this technique. Further research is also warranted investigating the timeline of both performance and ROM improvements with band flossing. For example, the current study showed improvements in jump performance and ROM ~5 minutes following the application of a floss band. Whether or not these benefits are still observed 5+ minutes following the use of this technique are yet to be determined. A limitation of the current study was that only one ankle was assessed with the floss band. It would be appropriate to apply the floss bands to both ankles and evaluate jumping and other lower-body performance parameters (e.g sprinting, leg strength and power). A further limitation in the current study was the lack of a placebo/sham condition. Indeed, the psychological advantage that may be associated with the intervention cannot be discounted. Future research may consider a parallel-group design that incorporates a placebo group.

Conclusion

The current study is the first study to describe the use of band flossing to improve ankle ROM and jump performance in recreational athletes. The potential benefits regarding the results of this study may have a significant impact in the sport setting. More specifically, our results would suggest that including band flossing on the ankle joint before taking part in any sports that require jumping actions, may not only improve performance, but may also provide a novel strategy for injury prevention, through increasing ankle ROM.

References

Batterham, A. M., & Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *International Journal of Sports Physiology and Performance, 1*(1), 50-57.

Bennell, K., Talbot, R., Wajswelner, H., Techovanich, W., Kelly, D., & Hall, A. (1998). Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. *Australian Journal of Physiotherapy, 44*(3), 175-180.

Bohlen, J., Arsenault, M., Deane, B., Miller, P., Guadagno, M., & Dobrosielski, D. (2014). *Effects of Applying Floss Bands on Regional Blood Flow.* Paper presented at the International Journal of Exercise Science: Conference Proceedings.

Brophy-Williams, N., Driller, M., Halson, S., Fell, J., & Shing, C. (2014). Evaluating the Kikuhime pressure monitor for use with sports compression clothing. *Sports Engineering, 17*(1), 55-60.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences. Vol. 2. *Lawrence Earlbaum Associates, Hillsdale, NJ.*

Conradsson, D., Fridén, C., Nilsson-Wikmar, L., & Ang, B. (2010). Ankle-joint mobility and standing squat posture in elite junior cross-country skiers. A pilot study. *The Journal of Sports Medicine and Physical Fitness, 50*(2), 132-138.

Fong, C.-M., Blackburn, J. T., Norcross, M. F., McGrath, M., & Padua, D. A. (2011). Ankle-dorsiflexion range of motion and landing biomechanics. *Journal of Athletic Training, 46*(1), 5-10.

Gabbe, B. J., Finch, C. F., Wajswelner, H., & Bennell, K. L. (2004). Predictors of lower extremity injuries at the community level of Australian football. *Clinical Journal of Sport Medicine, 14*(2), 56-63.

Griffin, L. Y., Albohm, M. J., Arendt, E. A., Bahr, R., Beynnon, B. D., DeMaio, M., Hannafin, J. A. (2006). Understanding and preventing noncontact anterior cruciate ligament injuries a review of the Hunt Valley II meeting, January 2005. *The American Journal of Sports Medicine, 34*(9), 1512-1532.

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Colosimo, A. J., McLean, S. G., Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes a prospective study. *The American Journal of Sports Medicine, 33*(4), 492-501.

Hori, N., & Andrews, W. (2009). Reliability of velocity, force and power obtained from the Gymaware optical encoder during countermovement jump with and without external loads. *Journal of Australian Strength and Conditioning, 17*(1), 12-17.

Lawson, C. S., & Downey, J. M. (1993). Preconditioning: state of the art myocardial protection. *Cardiovascular Research, 27*(4), 542-550.

Larson, G. (2014). *Examining ways to improve ankle mobility during the overhead squat lift.* University of Delaware.

Malliaras, P., Cook, J. L., & Kent, P. (2006). Reduced ankle dorsiflexion range may increase the risk of patellar tendon injury among volleyball players. *Journal of Science and Medicine in Sport, 9*(4), 304-309.

Morales, A. P., Sampaio-Jorge, F., da Cruz Rangel, L. F., de Oliveira Coe, G. M., Leite, T. C., & Ribeiro, B. G. (2014). Heart rate variability responses in vertical jump performance of basketball players. *International Journal of Sports Science, 4*(2), 72-78.

Pang, C. Y., Yang, R. Z., Zhong, A., Xu, N., Boyd, B., & Forrest, C. R. (1995). Acute ischaemic preconditioning protects against skeletal muscle infarction in the pig. *Cardiovascular Research, 29*(6), 782-788.

Plocker, D., Wahlquist, B., & Dittrich, B. (2015). *Effects of tissue flossing on upper extremity range of motion and power.* Paper presented at the International Journal of Exercise Science: Conference Proceedings.

Reeves, G. V., Kraemer, R. R., Hollander, D. B., Clavier, J., Thomas, C., Francois, M., & Castracane, V. D. (2006). Comparison of hormone responses following light resistance exercise with partial vascular occlusion and moderately difficult resistance exercise without occlusion. *Journal of Applied Physiology, 101*(6), 1616-1622.

Starrett, K., & Cordoza, G. (2013). Becoming A Supple Leopard. *The ultimate guide to resolving pain, preventing injury, and optimizing athletic performance*.

Tabrizi, P., McIntyre, W., Quesnel, M., & Howard, A. (2000). Limited dorsiflexion predisposes to injuries of the ankle in children. *Journal of Bone & Joint Surgery, British Volume, 82*(8), 1103-1106.

Takano, H., Morita, T., Iida, H., Asada, K.-i., Kato, M., Uno, K., Hirata, Y. (2005). Hemodynamic and hormonal responses to a short-term low-intensity resistance exercise with the reduction of muscle blood flow. *European Journal of Applied Physiology, 95*(1), 65-73.

Takarada, Y., Nakamura, Y., Aruga, S., Onda, T., Miyazaki, S., & Ishii, N. (2000). Rapid increase in plasma growth hormone after low-intensity resistance exercise with vascular occlusion. *Journal of Applied Physiology, 88*(1), 61-65.

Warren, B. L., & Jones, C. J. (1987). Predicting plantar fasciitis in runners. *Medicine and Science in Sports and Exercise, 19*(1), 71-73.

Youdas, J. W., Bogard, C. L., & Suman, V. J. (1993). Reliability of goniometric measurements and visual estimates of ankle joint active range of motion obtained in a clinical setting. *Archives of Physical Medicine and Rehabilitation, 74*(10), 1113-1118.