J Sci Cycling. Vol. 7(3), 11-44
DOI: 10.28985/181231.jsc.04

REVIEW ARTICLE

Open Access

Acute Post-Exercise Recovery Strategies in Cycling: A Review

Ryan Overmayer[1], Francisco Tavares[1] and Matthew Driller[1] ✉

Abstract

Cycling events often include multiple races a day or racing over consecutive days. Congested competition schedules and increased training load have led to the implementation of recovery strategies; with the goal of alleviating post-exercise fatigue and enhancing subsequent performance. This review aims to review the efficacy of recovery strategies used following different cycling events. Compression garments have been shown to improve subsequent 30s – 30min mean cycling power and 5-min max cycling power, while cold water immersion may improve 5-15s sprint cycling power output, 1-15min time trial (TT) total work performed and mean power output in hot and humid conditions. Cold water immersion was also more beneficial than active recovery at improving total work performed. Contrast water therapy could increase 15s – 15min TT work performed and sprint mean and peak power output. Similarly, active recovery has been shown to improve low intensity 3 – 15min cycling power and time to completion. Conversely, hot water immersion appears to be detrimental to sprint power output and TT power output over consecutive days. Thermoneutral water immersion appears beneficial for improving average cycling speed and time to completion during a 20-km TT, where humidification therapy and sports massage are beneficial at improving sprint and middle duration time trial performance. A combination of recovery strategies appear more beneficial than stand-alone strategies and various combinations should be explored further.

Keywords: fatigue; cyclist; cold water immersion; compression

✉ **Contact email:** mdriller@waikato.ac.nz (M Driller)

[1] Faculty of Health, Sport and Human Performance, University of Waikato, Hamilton, New Zealand

Received: 07 November 2018. Accepted: 28 December 2018.

Introduction

There are many disciplines in professional cycling such as track cycling, road cycling, mountain biking and bicycle motocross (BMX) (Edwards and Corte 2010; Jeukendrup et al. 2000; Marquet et al. 2015). These disciplines involve multiple races a day or racing over consecutive days (Marquet et al. 2015; Ménétrier et al. 2013; Versey et al. 2011). During training and congested competition schedules, recovery strategies are thought to alleviate post-exercise fatigue and enhance subsequent performance (Argus et al. 2013; Nédélec et al. 2013). 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 (Argus et al. 2013; Stanley et al. 2013). The main purpose of this review is to summarize the scientific literature on acute post-exercise recovery strategies implemented in the sport of cycling.

Liretature Search

The relevant literature for this review was obtained from a search within Google Scholar, MEDLINE/PubMed, SPORTDiscus, Web of Science and Cochrane databases. Based on a search of these databases, to our knowledge, there is currently no published review examining the literature on recovery strategies used with cyclists as the participants of interest. Included terms for the searches were: "cyclist/cycling" + either: "Recovery strategies", "cold water immersion", "active recovery", "electromyostimulation", "massage recovery", "compression garments recovery", "cryotherapy", "water immersion recovery", "hydrotherapy recovery", "static stretching recovery", "dynamic stretching recovery", "ice". The inclusion criteria was limited to the English language and studies published prior to 2018. Studies which examined cycling but did not use cyclists as subjects were excluded from the review. Studies which examined cycling but did not use cyclists as subjects were excluded from the review. The rationale for this was to provide an accurate representation of the impact of recovery strategies when used in a relevant context for practitioners; with cyclists and in cycling settings. 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 (Craig and Norton 2001). 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 (Black et al. 2017; Jeukendrup et al. 2000). Therefore, cycling events have been categorized with race duration (Table 1). The following section provides a general overview of fatigue associated with the category durations provided.

Fatigue During Sprint Cycling

Humans possess Adenosine Triphosphate (ATP) reserves for ~2 seconds of maximal contraction (Cramer 2008; Kenney et al. 2015). 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 (Kenney et al. 2015). In a brief event such as sprint cycling (i.e. 200m track sprint), energy production is highly dependent on the anaerobic system (Jeukendrup et al. 2000). For example, during a 200m track sprint, the alactic and anaerobic systems contribute 40 and 55% of energy production, respectively (Jeukendrup et al. 2000). Therefore, performance decrements in these events have been attributed to a combination of 'peripheral metabolic' and 'central/neural' mechanisms (Craig and Norton 2001; Gardner et al. 2009). 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 (Temesi et al. 2017). 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 fibers, responsible for maximal force production (Gardner et al. 2009; Phillips 2015). Thus, a reduction in the capability to recruit fast twitch MU, will ultimately result in a reduction of power output during sprint cycling (Gardner et al. 2009).

Table 1. Men's cycling events categorised according to duration.

Category	Duration	Events
Sprint	0 – 30 sec	Track Omnium Flying Lap (12.51s)*
Short-duration	30 – 120 sec	Track Team Sprint (42.44s)* BMX (34.64s)* Track Omnium 1-km TT (60.92s)*
Middle-duration	2 min – 30 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 30 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 Short-Duration Cycling

During short-duration events (Table 1), both the anaerobic and aerobic systems contribute to the vast majority of energy production (Jeukendrup et al. 2000). For example, during a female 500m cycling sprint (duration ~35s), the anaerobic glycolytic and aerobic contribution is suspected to be 45 & 35%, respectively (Jeukendrup et al. 2000). Moreover, the anaerobic glycolytic and aerobic contribution during a male 1000m track cycling event (duration ~60s) is suspected to be 40

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	Full length tights	27 ± 6	18 ± 2	Kikuhime
Driller & Halson, 2013	Full length tights	21 ± 3	12 ± 3	Unpublished observations
Chatard et al., 2004	Compression stockings	18	12	Manufacturer report
Ménétrier et al., 2013	Compression stockings	27	14	Manufacturer report
Argus et al., 2013	Full length tights	27 ± 6	18 ± 2	Kikuhime

& 50%, respectively (Jeukendrup et al. 2000). Conversely, the alactic system is believed to only contribute 10-20% of total energy production during events of this duration (Jeukendrup et al. 2000). The dependency on the anaerobic glycolytic system is associated with an increase in metabolites and therefore a loss of muscle function (Cairns 2006; Robergs et al. 2004; Westerblad et al. 2002). While traditionally thought that increased H^+ was the main metabolite which contributed to fatigue (Cairns 2006), Degroot and

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	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	Highly trained cyclists (VO_{2max} = 66.6 ± 3.8 mL·Kg^{-1}·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	Trained elderly cyclists (VO_{2max} = 49 ± 6 mL·Kg^{-1}·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	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 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 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.

colleagues (Degroot et al. 1993) 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 (Cairns 2006; Robergs et al. 2004; Westerblad et al. 2002).

Fatigue During Middle-Duration Cycling

Middle-duration events in cycling range from a duration of between 2 to 30-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%) (Jeukendrup et al. 2000). For example, in the male 4-km TT (~4 min duration) the anaerobic glycolytic system contributes 14% of energy production, while the aerobic system contributes a greater 85% of energy production (Jeukendrup et al. 2000). 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 (Abbiss and Laursen 2005). 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 (Jones et al. 2010). Performing above CP during cycling tasks has been linked to a reduction of muscle PCr, ATP and a concomitant increase in P_i, plasma potassium ion (K^+) and blood and muscle lactate (Black et al. 2017). 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 (Black et al. 2017). 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 (Allen et al. 2008).

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 (Abbiss and Laursen 2005). Given the duration of these events, energy is predominantly produced from the aerobic system (Jeukendrup et al. 2000). As with middle-duration cycling, a limiting factor of performance is the ability of the cardiovascular system to supply sufficient oxygen to the working muscle (Abbiss and Laursen 2005). 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 (Black et al. 2017). Additionally, prolonged endurance cycling results in severe depletion of liver and muscle glycogen (Abbiss and Laursen 2005; Black et al. 2017) and reductions in voluntary strength (Millet and Lepers 2004). A further explanation for an increase in fatigue and consequent reduction in power output could be mechanical damage, resulting from muscle cell disruption (Mena et al. 1996).

Recovery Modalities in Cycling

Compression Garments (COMP)

Compression garments (COMP) are thought to improve exercise recovery through the application of pressure at the extremity i.e. ankle, thereby enhancing venous blood flow which in turn, assists in the removal of metabolic waste accumulated as a result of exercise (Argus et al. 2013). There are three types of COMP that have been examined in cycling literature: Compression stockings (Chatard et al. 2004; Ménétrier et al. 2013), full-length tights (Argus et al. 2013; Driller and Halson 2013) and dynamic compression (Overmayer and Driller, 2018). The ability of COMP 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 maximal power, decrease thigh girth, calf girth and perceived muscle soreness post-recovery when compared with a passive control (CON) (Argus et al. 2013; Chatard et al. 2004; Driller and Halson 2013; Ménétrier et al. 2013). However, it is worth noting that not all studies quantified the actual pressure exerted by the garments used (Table 2). While Dynamic compression requires further studies, currently there seems to be no benefit when used between a 20-min and 4-min TT (Overmayer and Driller, 2018). COMP used for between 12 – 80mins post-exercise has been shown to improve 5-min maximal cycling mean and max power by up to 2.1 %, 30s cycling mean power by 0.8 % (however the SD was 1.2 %) and 30-min cycling mean power by 2 % (Table 3). Full length tights and compression stockings used for 12-80mins improved the rate of blood lactate (BLa) removal following 10-min cycling beginning at 80% and increasing to 90% PPO, 30-min cycling beginning at 70% and increasing to 100% peak power output (PPO) and 5-mins of maximal cycling (Chatard et al. 2004; Driller and Halson 2013; Ménétrier et al. 2013). However, full length tights were no more beneficial than passive rest alone, at reducing BLa concentration following 30s of maximal sprint cycling (Argus et al. 2013). Furthermore, COMP resulted in no change in HR measures, TQR (Perceived Total Quality Recovery) or RPE (Rating of Perceived Exertion) when compared with CON (Argus et al. 2013; Chatard et al. 2004; Ménétrier et al. 2013). It should not be discounted that a placebo effect is responsible, at least in part, for the resultant performance benefits; a study by Argus and colleagues (Argus et al. 2013) attempted to account for a possible 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 the placebo effect alone may not be responsible for the resultant performance benefits associated with COMP.

Future research should continue to use a valid and reliable method of pressure monitoring such as the Kikuhime (Brophy-Williams et al. 2014) 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 (Brophy-Williams et al. 2016) to examine the placebo effect. Dynamic compression is a relatively new area of research and requires further examination in cyclists.

Cold Water Immersion (CWI)

Cold water immersion is the most researched recovery strategy in the cycling literature (Table 4). CWI has been suggested beneficial for the treatment of inflammation and perceived pain (Vaile et al. 2011). Due to the large number of studies examining CWI in cyclists, performance recovery and physiological variables will be examined separately for this recovery modality.

Three studies have reported improvements in power measures (Peiffer et al. 2008a; Stanley et al. 2013; Vaile et al. 2008b) while a further six studies report no significant difference following CWI (Buchheit et al. 2009; Chan et al. 2016; Christensen and Bangsbo 2016; Peiffer et al. 2008b; Stanley et al. 2012; Stanley et al. 2013) and only one study reported CWI as detrimental to power output (Schniepp et al. 2002). During a 4-km TT in the heat (35°C), power output was reduced by 20 ± 6% in CON, where CWI was able to attenuate this decrement to only a 3 ± 3% reduction in power output and improved time to completion by 18 ± 11.5 sec (Peiffer et al. 2008a). During 66 ramped sprints beginning at 5s and working up to 15s per sprint, CWI was able to improve sprint power measures by 2.4 % over 3 days (Stanley et al. 2013) and 1.4 % over 5 days (Vaile et al. 2008b) when compared with CON. Following the aforementioned sprint cycling protocol, CWI improved 9-min TT mean power by up to 1% over 5 days, where CON reduced power by up to 3.8%, this improvement in power was also associated with an improvement in total work performed on days 4 & 5 (Vaile et al. 2008b). 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 (Buchheit et al. 2009; Peiffer et al. 2008b). Further studies had extensive recovery durations (over 2 hours) which may have diluted the impact of the recovery intervention (Christensen and Bangsbo 2016; Stanley et al. 2012). Stanley and colleagues (Stanley et al. 2013) reported no significant difference in power during TT cycling. However, these TT were preceded by 66 ramped sprints from which they saw CWI attenuated sprint power by up to 12% over 3 days when compared with CON; 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 (Schniepp et al. 2002), 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). Studies that examined subsequent performance and reported benefits from the use of CWI had an acclimation period consisting of a significant warm-up (Vaile et al. 2008b) or 10-mins passive rest post CWI (Peiffer et al. 2008a), where Schniepp and colleagues (Schniepp et al. 2002) 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 (Schniepp et al. 2002) which perhaps is mitigated by the use of passive rest or a warm-up post condition.

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 (Vaile et al. 2011). In an earlier study by Vaile and colleagues (Vaile et al. 2008a) 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 %. Only one study revealed no significant difference in total work performed from the use of CWI (Peiffer et al. 2007) and can be attributed to a long recovery duration consisting of 1.5hrs before the performance trial (Peiffer et al. 2007).

CWI's impact on isometric and isokinetic force production following cycling is confounding. Maximum voluntary isometric contraction was reduced from the use of CWI 45 & 90-mins post 16.1km TT when compared to CON (Peiffer et al. 2007). 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, 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 (Peiffer et al. 2008b; Peiffer et al. 2009) revealed no significant difference in isometric and isokinetic torque.

CWI decreased HR post-recovery by 4.2 % when used for 15-mins between sprint cycling of 30s (Schniepp et al. 2002). In addition to improved HR post-recovery, CWI consistently increased HRV measures with *large* effect sizes (Buchheit et al. 2009; Stanley et al. 2012; Stanley et al. 2013).

Perceived recovery measures revealed that CWI improved ratings of perceived physical and mental recovery, reduced perceived muscle soreness and perceived general fatigue (Buchheit et al. 2009; Halson et al. 2008). Stanley and colleagues (Stanley et al. 2012; Stanley et al. 2013) also revealed similar improvements in a reduction of perceived general fatigue, leg soreness and an increase in physical recovery however, no significant difference and *unclear* effect sizes were observed in mental recovery and perceived tiredness. Christensen and Bangsbo (2016) was the only study to examine perceived readiness and results revealed there was no change between conditions.

BLa results revealed no significant difference following a 4-min TT (Christensen and Bangsbo 2016) and a 40-min TT in heat (Halson et al. 2008). Unfortunately subsequent performance wasn't examined in these studies.

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	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, 2008a	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, 2008b	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	Male cyclists (age = 29 ± 3 years; VO_{2max} = 64.0 ± 5.7 mL·Kg^{-1}·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	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	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 ∆rMSSD (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 ↑ ∆rMSSD vs CON (*large* effect size) CWI ↑ ∆rMSSD 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 ↑ ∆rMSSD and ↓ perceived leg soreness CWI > CWT ↑ ∆rMSSD ↓ and perceived general fatigue CWI > CON ↓ perceived general fatigue and ↑ perceived physical recovery CWT > CWI ↑ perceived physical recovery

Stanley et al, 2012	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

Vaile et al, 2008a	Well-trained male cyclists (age = 32 ± 5 years; VO_{2max} = 70.7 ± 7.9 mL·Kg^{-1}·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 ↑ HRpost-intervention vs all CWI conditions (ICWI10: 86 ± 12 b·min-1, ICWI15: 80 ± 7 b·min-1, CWI20: 81 ± 12 b·min-1, CCWI20: 81 ± 9 b·min-1, AR: 128 ± 7 b·min-1, $p < 0.001$) AR ↑ HRpost-recovery vs ICWI10, ICWI15 & CCWI20 (ICWI10: 74 ± 13 b·min-1, ICWI15: 69 ± 8 b·min-1, CCWI20: 71 ± 8 b·min-1, AR: 87 ± 11 b·min-1,) but not ICWI20 (ICWI20: 80 ± 6 b·min-1) but not ICWI20 (ICWI20: 80 ± 6 b·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, 2008b	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	Endurance trained male cyclists (age = 33.7 ± 4.7 years; VO_{2max} = 66.7 ± 6.1 mL·Kg^{-1}·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·min^{-1}, AR: 90 ± 11 b·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	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)	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	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	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.

Road cycling events result in short resting durations and in events such as stage races, the resting location is not always the same (Chan et al. 2016). Therefore, CWI is not always practical as it would require a movable immersion pool and as a result, Chan and colleagues (Chan et al. 2016) have examined the use of a dynamic form of cold compression (Game Ready; CoolSystems, Concord, CA, USA). 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 15 °C x 15-mins has been shown beneficial for improving 1-15min TT total work performed, while 10 °C – 15 °C used for 5-14mins is better utilized during 5 – 15s sprints for mean power output improvements and 14 °C x 5-mins can enhance subsequent 4km (4-5mins) average power output and time to completion. 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 and increased perceived recovery. CWI may not 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, therefore, a passive seated CON 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.

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) (Ménétrier et al. 2013). It is proposed that CWT improves muscle soreness, inflammation and performance recovery (Vaile et al. 2008b).

Thermoneutral water immersion (TWI) can be described as exposure to temperate-water, typically around 26°C and has been suggested as effective in the removal of heat when exercise hyperthermia is of concern. Therefore, in order to maintain exercise performance following exercise in hot and humid conditions, TWI may be as effective as CWI (Lit et al. 2014). Indeed, it has been suggested that a reduction in muscle temperature can impair cross-bridge cycling, motor unit activation and enzyme activity rate (Schniepp et al. 2002); 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 (Vaile et al. 2008b). Whether or not hot water immersion is beneficial to exercise recovery and performance, or the physiological mechanisms by which HWI would impact these variables are unknown (Vaile et al. 2008b).

CWT has been shown more beneficial than passive rest alone and appears dose-dependent with 6-mins shown to improve 15-min TT total work performed, where 12-mins and 18-mins had no significant difference on total work performed (Versey et al. 2011). In the same study, both 6 and 12-mins improved 5 x 15s sprint total work performed, where 18-mins was again ineffective (Versey et al. 2011). When examining PPO, CWT used for 12-mins was more beneficial than both 6-mins, 18-mins and CON (Versey et al. 2011). 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 % (Ménétrier et al. 2013). Fourteen minutes of CWT 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 (Vaile et al. 2008b). 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 (Vaile et al. 2008b).

One study exhibited no improvements in time to completion or power output from the use of CWT when compared with CON (Stanley et al. 2012). 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, the same study that reported no benefit from the use of CWT used a 190-min recovery period, which would have diluted the impact of the intervention.

Based on the evidence, CWT (15°C CWI :38°C HWI; 1:1-mins) used for 14-mins is recommended for a 9-min TT, 6-mins is recommended for up to a 15min TT, while 12-mins appears more beneficial for a 15s sprint. When the HWI:CWI ratio extended to 1-min CWI and 2-min HWI, 5-min TT total work improved. These benefits were associated with a reduction in BLa of 2.7 $mmol \cdot L^{-1}$ (Ménétrier et al. 2013), a decrease in perceived muscle

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	Trained male cyclists representing Kelantan state (age = 19 ± 5 years; VO_{2max} = 58 ± 4 mL·Kg^{-1}·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·min^{-1}, CON: 168 ± 5 b·min^{-1}) and post-recovery HR (TWI: 62 ± 10 b·min^{-1}, CON: 90 ± 8 b·min^{-1}, $p < 0.001$) vs CON TWI ↓ T_{re} 15-mins during recovery ($p < 0.05$) and post-recovery (post recovery ∆ 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	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	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, 2008b	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	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 ∆rMSSD (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 ↑ ∆rMSSD vs CON (*large* effect size) CWI ↑ ∆rMSSD 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 ↑ ∆rMSSD and ↓ perceived leg soreness CWI > CWT ↑ ∆rMSSD ↓ and perceived general fatigue CWI > CON ↓ perceived general fatigue and ↑ perceived physical recovery CWT > CWI ↑ perceived physical recovery

VO2max 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, Tre 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, HRmax maximum heart rate, AR active recovery, rMSSD natural logarithm of the square root of mean squared differences of successive R-R intervals.

soreness, whole body fatigue (Ménétrier et al. 2013; Versey et al. 2011) and core-temperature post-recovery when used for 12 & 18-mins (Versey et al. 2011). 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 (Versey et al. 2011). Surprisingly, subjects reported a reduction in perceived motivation when CWT was used for 12-mins (Versey et al. 2011).

HWI appears detrimental to mean power output and a rise of core temperature beyond 39°C can result in increased perceived fatigue, a reduction in exercise performance and premature exercise termination (Peiffer et al. 2008a; Vaile et al. 2008a). Therefore, a recovery strategy that aims to expose athletes to HWI alone seems counterintuitive, unless perhaps in cold-weather racing, and future studies should examine the impact of weather conditions on the effectiveness of recovery methods.
TWI has been shown greater than passive rest alone at reducing 20-km TT time to completion and improving average speed (Lit et al. 2014). This improvement in performance was associated with a reduction in T_{re} and increased HR recovery. The use of TWI seems promising and future research should use four conditions and compare TWI, CWI, CWT and CON to determine the most effective form of water immersion.

Electromyostimulation (EMS)
Only one study to our knowledge, has examined electromyostimulation/electronic muscle stimulation (EMS) on cyclists during a cycling exercise protocol (Table 6) (Argus et al. 2013). 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, aids in the removal of metabolites, decreases muscle soreness and ultimately restores neuromuscular function and exercise performance (Babault et al. 2011). In the study by Argus and colleagues (Argus et al. 2013), 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 CON (4.9 ± 6.9 %) and EMS was able to improve participant's perceived recovery (0.7 ± 0.9). While further research is necessary to support the current findings, EMS appears to be an effective strategy at 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.

Humidification Therapy (HUM)
The aforementioned study which examined EMS (Argus et al. 2013), also examined a novel strategy called Humidification Therapy (HUM) on cyclists (Table 7). 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 (Argus et al. 2013; Hasani et al. 2008). In the study by Argus and colleagues (Argus et al. 2013), 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 CON (2.2 ± 2.5 %). In conjunction with improved power measures, HUM was able to reduce BLa levels during the recovery period (4.3 ± 7.9 %).
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.

Sports Massage (SM)
Sports massage is commonly used to attenuate muscular fatigue (Bielik 2010) and it is believed that through sports massage, there is an increase in blood flow which assists in the removal of metabolic waste (Martin et al. 1998). 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 (Paoli et al. 2013). In the study by Paoli and colleagues (Paoli et al. 2013) SMOZO increased PPO by up to 30W following anaerobic cycling when compared with SM alone and CON. Bielik and colleagues (Bielik 2010) revealed no statistically significant difference between SM and CON 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, a combination of both AR and SM were more effective than either SM or passive recovery alone and reduced subsequent performance time by up to 7s over 5km (Monedero and Donne 2000). Due to SM potential 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 (Martin et al. 1998) and AR shown to be more beneficial than SM at reducing BLa post-recovery (Table 8) (Bielik 2010; Martin et al. 1998; Monedero and Donne 2000). Consistent with performance results, both SMOZO and a combination of AR and SM, prove more effective than both SM alone

and CON at reducing BLa (Monedero and Donne 2000; Paoli et al. 2013). Psychologically, SM both with and without ozonised oil were more beneficial than CON at reducing perceived fatigue (Paoli et al. 2013). Nevertheless, SMOZO was still more effective than SM alone. SM was more beneficial than AR at reducing HR measures (Bielik 2010; Monedero and Donne 2000) but also revealed no difference when compared with CON or SMOZO (Paoli et al. 2013). 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, subsequent 30s power output and 5-9min TT performance time.

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	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.

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	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.

Static Stretching (SS)

To our knowledge, the current research evaluating static stretching (SS) on cyclists is limited to one study (Table 9) (Kingsley et al. 2013). SS, while beneficial for increasing range of motion (RoM), has been shown to temporarily decrease muscular power (Costa et al. 2013; Samuel et al. 2008). In the study by Kingsley and colleagues (Kingsley et al. 2013), 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 was performed were not described. While no significant difference was observed, SS resulted in a 0.86% increase in absolute PPO and increased relative peak power output (+0.86 %) when compared with QR. The use of Cohen's *d* effect size analysis would have been a worthwhile tool to better evaluate the findings of the study. As expected, SS improved RoM and resulted in a 2.1cm increase in sit and reach distance. With limited research, it is difficult to interpret the efficacy of SS. However, based on the aforementioned study, 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 (Asplund and St Pierre 2004). Therefore, performing quadriceps, hamstring and ITB stretching between exercise bouts could be beneficial.

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	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	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	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	Trained male cyclists (age = 25 ± 1 years; VO_{2max} = 68 ± 1.7 mL·Kg^{-1}·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

Active Recovery (AR)

Active recovery can be described as gentle exercise between exercise bouts; believed to enhance metabolic waste removal and improve subsequent performance (Chan et al. 2016). 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 (Bielik 2010; Monedero and Donne 2000). 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 (Bielik 2010). 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 (Connolly et al. 2003) 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 CON. The use of AR in an anaerobic setting was further supported by Bielik and colleagues (Bielik 2010) 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) and mean power output (CON: 678 ± 45, AR: 746 ± 47 W) 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 (Monedero and Donne 2000). 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 (Chan et al. 2016; Martin et al. 1998; Vaile et al. 2008a; Vaile et al. 2011). Comparing against CWI is difficult to interpret, as CWI has been shown to improve subsequent performance when compared with passive rest (Peiffer et al. 2008a; Stanley et al. 2013; Vaile et al. 2008b).

AR was able to attenuate BLa concentration by 21-54% more than that of CON (Bielik 2010; Martin et al. 1998; Monedero and Donne 2000). However, one study revealed no significant difference in BLa levels following AR (Connolly et al. 2003) and this could have been due to a shorter recovery duration of only 3-min intervals (Connolly et al. 2003). 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. A novel form of AR has been examined by performing active recovery in

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	Aerobically trained cyclists (age = 21 ± 2 years; VO_{2max} = 42.0 ± 5.6 $mL \cdot Kg^{-1} \cdot min^{-1}$) 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.

water (ARW) (Ferreira et al. 2011). 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 use of AR at 80RPM for 3-mins may improve 15s sprint cycling power output, AR at 50% VO_{2max} for 15-mins can improve 5km TT performance time and 20-40% VO_{2max} for 20-mins can improve 30s peak and mean power output. 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 exercise 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	80rpm (1Kg resistance)	3-mins	Yes	+
Joanna Vaile et al., 2008a	40% VO_{2max}	15-mins	No	-
Vaile et al., 2011	40% PPO	15-mins	No	-
Chan et al., 2016	40% PPO	15-mins	No	=
Monedero & Donne, 2000	50% VO_{2max}	15-mins	Yes	+
Martin et al., 1998	40% VO_{2max} / 80rpm	20-mins	Yes	n/a
Bielik, 2010	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	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	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	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	Trained male cyclists (age = 25 ± 1 years; VO_{2max} = 68 ± 1.7 mL·Kg^{-1}·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	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, 2008a	Well-trained male cyclists (age = 32 ± 5 years; VO_{2max} = 70.7 ± 7.9 mL·Kg^{-1}·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 $HR_{post-intervention}$ $HR_{post-recovery}$	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 ↑ HRpost-intervention vs all CWI conditions (ICWI10: 86 ± 12 b·min-1, ICWI15: 80 ± 7 b·min-1, CWI20: 81 ± 12 b·min-1, CCWI20: 81 ± 9 b·min-1, AR: 128 ± 7 b·min-1, $p < 0.001$) AR ↑ HRpost-recovery vs ICWI10, ICWI15 & CCWI20 (ICWI10: 74 ± 13 b·min-1, ICWI15: 69 ± 8 b·min-1, CCWI20: 71 ± 8 b·min-1, AR: 87 ± 11 b·min-1,) but not ICWI20 (ICWI20: 80 ± 6 b·min-1) but not ICWI20 (ICWI20: 80 ± 6 b·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	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 ∆: -1.8 ± -1.1 %) CWI ↑ total work performed (pre to post ∆: +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	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 $mmol \cdot L^{-1}$, PRW: 4.71 ± 1.08 $mmol \cdot L^{-1}$, PRL: 4.52 ± 1.23 $mmol \cdot L^{-1}$, $p < 0.05$) 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.

Conclusions

The use of COMP between 12 – 80mins post-exercise has been shown to improve subsequent 5-min maximal cycling mean and max power output, 30s cycling mean power and 30-min cycling mean power (Argus et al. 2013; Chatard et al. 2004; Driller and Halson 2013; Ménétrier et al. 2013). 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 (Peiffer et al. 2008a). CWI used for 14-15mins at 15°C appears advantageous for improving 9-15min TT total work performed and repeated sprint power output (Vaile et al. 2008a; Vaile et al. 2008b; Vaile et al. 2011). CWI also appears more beneficial than AR at improving total work performed (Vaile et al. 2011). CWT used between 6-14mins with 38°C HWI and 15°C CWI and a ratio of cold:hot 1:1-mins or 1:2-mins, could increase subsequent TT total work performed, TT & sprint mean power output and sprint PPO (Ménétrier et al. 2013; Vaile et al. 2008b). This performance benefit from CWT has been observed from durations as short as a 15s sprint and up to a 15-min TT (Ménétrier et al. 2013; Vaile et al. 2008b). HWI alone appears to be detrimental to performance (Vaile et al. 2008b), while TWI has been shown to decrease 20-km TT time to completion and improve average cycling speed (Lit et al. 2014). Both HUM and EMS may be able to attenuate the decrement in 30s sprint mean power (Argus et al. 2013). SMOZO may assist time trial cycling performance (Paoli et al. 2013) and SM may improve anaerobic cycling mean power and reduce 5-km TT time to completion (Bielik 2010; Monedero and Donne 2000). 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 (Monedero and Donne 2000). The use of SS did not inhibit anaerobic cycling performance when performed for 3 x 30s per muscle and leg (Kingsley et al. 2013) 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 (Asplund and St Pierre 2004). AR has been shown to attenuate 15s sprint PPO, 5km TT time to completion and even increase 30s sprint cycling mean power and PPO (Bielik 2010; Connolly et al. 2003; Monedero and Donne 2000).

A number of gaps exist in the current literature investigating the use of recovery techniques in cycling. Future research should aim to determine the influence of recovery strategies on multiple-day stage races (e.g. tours) and the also the influence of both CWI and HWI in different temperature environments. There is a paucity of research examining the use of recovery techniques in trained female cyclists and also the use of recovery strategies in a chronic (e.g. > 4 weeks) setting. Addressing these areas of future research will ensure a greater understanding of the use of recovery techniques and strategies in the sport of cycling.

Conflict of Interest

None

References

1. Abbiss C, Laursen P (2005) Models to explain fatigue during prolonged endurance cycling. Sports Medicine 35: 865-898
2. Allen D, Lamb G, Westerblad H (2008) Skeletal muscle fatigue: cellular mechanisms. Physiological reviews 88: 287-332
3. Argus C, Driller M, Ebert T, Martin D, Halson S (2013) The effects of 4 different recovery strategies on repeat sprint-cycling performance. International Journal of Sports Physiology and Performance 8: 542-548
4. Asplund C, St Pierre P (2004) Knee pain and bicycling: fitting concepts for clinicians. The Physician and sportsmedicine 32: 23-30
5. Babault N, Cometti C, Maffiuletti N, Deley G (2011) Does electrical stimulation enhance post-exercise performance recovery? European Journal of Applied Physiology 111: 2501-2507
6. Bielik V (2010) Effect of different recovery modalities on anaerobic power in off-road cyclists. Biology of Sport 27: 59-63
7. Black M, Jones A, Blackwell J, Bailey S, Wylie L, McDonagh S, Thompson C, Kelly J, Sumners P, Mileva K (2017) Muscle metabolic and neuromuscular determinants of fatigue during cycling in different exercise intensity domains. Journal of Applied Physiology 122: 446-459
8. 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: 55-60
9. Brophy-Williams N, Driller M, Kitic C, Fell J, Halson S (2016) Effect of compression socks worn between repeated maximal running bouts. International Journal of Sports Physiology and Performance 12: 1-22
10. Buchheit M, Peiffer J, Abbiss C, Laursen P (2009) Effect of cold water immersion on postexercise parasympathetic reactivation. American Journal of Physiology-Heart and Circulatory Physiology 296: H421-H427
11. Cairns S (2006) Lactic acid and exercise performance. Sports Medicine 36: 279-291
12. Chan Y-Y, Yim Y-M, Bercades D, Cheng TT, Ngo K-L, Lo K-K (2016) Comparison of different cryotherapy recovery methods in elite junior cyclists. Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology 5: 17-23
13. Chatard J, Atlaoui D, Farjanel J, Louisy F, Rastel D, Guézennec C (2004) Elastic stockings, performance and leg pain recovery in 63-year-old sportsmen. European Journal of Applied Physiology 93: 347-352
14. Christensen P, Bangsbo J (2016) Influence of prior intense exercise and cold water immersion in recovery for performance and physiological response during subsequent exercise. Frontiers in Physiology 7: 1-10
15. Connolly D, Brennan K, Lauzon C (2003) Effects of active versus passive recovery on power output during repeated bouts of short term, high intensity exercise. Journal of Sports Science & Medicine 2: 47-51

16. Costa P, Ryan E, Herda T, Walter A, DeFreitas J, Stout J, Cramer J (2013) Acute effects of static stretching on peak torque and the hamstrings-to-quadriceps conventional and functional ratios. Scandinavian Journal of Medicine & Science in Sports 23: 38-45
17. Craig N, Norton K (2001) Characteristics of track cycling. Sports Medicine 31: 457-468
18. Cramer J (2008) Bioenergetics of exercise and training. Human Kinetics, Champaign, IL
19. Degroot M, Massie B, Boska M, Gober J, Miller R, Weiner M (1993) Dissociation of [H+] from fatigue in human muscle detected by high time resolution 31P-NMR. Muscle & nerve 16: 91-98
20. Driller M, Halson S (2013) The effects of lower-body compression garments on recovery between exercise bouts in highly-trained cyclists. Journal of Science and Cycling 2: 45-50
21. Edwards B, Corte U (2010) Commercialization and lifestyle sport: lessons from 20 years of freestyle bmx in 'pro-town, USA'. Sport in Society 13: 1135-1151
22. Ferreira J, Da Silva Carvalho R, Barroso T, Szmuchrowski L, Śledziewski D (2011) Effect of different types of recovery on blood lactate removal after maximum exercise. Polish Journal of Sport and Tourism 18: 105-111
23. Gardner S, Martin D, Jenkins D, Dyer I, Van Eiden J, Barras M, Martin J (2009) Velocity-specific fatigue: quantifying fatigue during variable velocity cycling. Medicine & Science in Sports & Exercise 41: 904-911
24. Halson S, Quod M, Martin D, Gardner A, Ebert T, Laursen P (2008) Physiological responses to cold water immersion following cycling in the heat. International Journal of Sports Physiology and Performance 3: 331-346
25. Hasani A, Chapman T, McCool D, Smith R, Dilworth J, Agnew J (2008) Domiciliary humidification improves lung mucociliary clearance in patients with bronchiectasis. Chronic Respiratory Disease 5: 81-86
26. Jeukendrup A, Craig N, Hawley J (2000) The bioenergetics of world class cycling. Journal of Science and Medicine in Sport 3: 414-433
27. Jones A, Vanhatalo A, Burnley M, Morton R, Poole D (2010) Critical power: implications for determination of VO_{2max} and exercise tolerance. Medicine & Science in Sports & Exercise 42: 1876-1890
28. Kenney W, Wilmore J, Costill D (2015) Physiology of Sport and Exercise 6th Edition. Human Kinetics, Champaign, IL
29. Kingsley D, Zakrajsek R, Nesser T, Gage M (2013) The effect of motor imagery and static stretching on anaerobic performance in trained cyclists. The Journal of Strength & Conditioning Research 27: 265-269
30. Lit K, Chen C, Ang B (2014) Effects of acute cool water immersion on time trial performance and exercised-induced oxidative stress among endurance cyclists in the heat. Journal of Athletic Enhancement 3: 1-5
31. Marquet A-L, Hausswirth C, Hays A, Vettoretti F, Brisswalter J (2015) Comparison of between-training-sessions recovery strategies for world-class bmx pilots. International Journal of Sports Physiology and Performance 10: 219-223
32. Martin N, Zoeller R, Robertson R, Lephart S (1998) The comparative effects of sports massage, active recovery, and rest in promoting blood lactate clearance after supramaximal leg exercise. Journal of Athletic Training 33: 30-35
33. Mena P, Maynar M, Campillo J (1996) Changes in plasma enzyme activities in professional racing cyclists. British Journal of Sports Medicine 30: 122-124
34. Ménétrier A, Pinot J, Mourot L, Grappe F, Bouhaddi M, Regnard J, Tordi N (2013) Effects of recovery using contrast water therapy or compression stockings on subsequent 5-min cycling performance. Journal of Science and Cycling 2: 49-56
35. Millet G, Lepers R (2004) Alterations of neuromuscular function after prolonged running, cycling and skiing exercises. Sports Medicine 34: 105-116
36. Monedero J, Donne B (2000) Effect of recovery interventions on lactate removal and subsequent performance. International Journal of Sports Medicine 21: 593-597
37. Nédélec M, McCall A, Carling C, Legall F, Berthoin S, Dupont G (2013) Recovery in soccer. Sports Medicine 43: 9-22
38. Overmayer R, Driller M (2018).
39. Paoli A, Bianco A, Battaglia G, Bellafiore M, Grainer A, Marcolin G, Cardoso CC, Dall'Aglio R, Palma A (2013) Sports massage with ozonised oil or non-ozonised oil: comparative effects on recovery parameters after maximal effort in cyclists. Physical Therapy in Sport 14: 240-245
40. Peiffer J, Abbiss C, Nosaka K, Peake J, Laursen P (2007) Effect of cold water immersion after exercise in the heat on muscle function, body temperatures, and vessel diameter. Journal of Science and Medicine in Sport 12: 91-96
41. Peiffer J, Abbiss C, Watson G, Nosaka K, Laursen P (2008a) Effect of a 5-min cold-water immersion recovery on exercise performance in the heat. British Journal of Sports Medicine 44: 461-465
42. Peiffer J, Abbiss C, Watson G, Nosaka K, Laursen P (2008b) Effect of cold water immersion on repeated 1-km cycling performance in the heat. Journal of Science and Medicine in Sport 13: 112-116
43. Peiffer J, Abbiss C, Watson G, Nosaka K, Laursen P (2009) Effect of cold-water immersion duration on body temperature and muscle function. Journal of Sports Sciences 27: 987-993
44. Phillips S (2015) Fatigue in sport and exercise. Routledge, New York, NY
45. Robergs R, Ghiasvand F, Parker D (2004) Biochemistry of exercise-induced metabolic acidosis. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology 287: R502-R516
46. Samuel M, Holcomb W, Guadagnoli M, Rubley M, Wallmann H (2008) Acute effects of static and ballistic stretching on measures of strength and power. The Journal of Strength & Conditioning Research 22: 1422-1428

47. Schniepp J, Campbell T, Powell K, Pincivero D (2002) The effects of cold-water immersion on power output and heart rate in elite cyclists. The Journal of Strength & Conditioning Research 16: 561-566
48. Stanley J, Buchheit M, Peake J (2012) The effect of post-exercise hydrotherapy on subsequent exercise performance and heart rate variability. European Journal of Applied Physiology 112: 951-961
49. Stanley J, Peake J, Buchheit M (2013) Consecutive days of cold water immersion: effects on cycling performance and heart rate variability. European Journal of Applied Physiology 113: 371-384
50. Temesi J, Mattioni-Maturana F, Peyrard A, Piucco T, Murias J, Millet G (2017) The relationship between oxygen uptake kinetics and neuromuscular fatigue in high-intensity cycling exercise. European Journal of Applied Physiology 117: 969-978
51. Vaile J, Halson S, Gill N, Dawson B (2008a) Effect of cold water immersion on repeat cycling performance and thermoregulation in the heat. Journal of Sport Science 26: 431-440
52. Vaile J, Halson S, Gill N, Dawson B (2008b) Effect of hydrotherapy on recovery from fatigue. International Journal of Sports Medicine 29: 539-544
53. Vaile J, O'Hagan C, Stefanovic B, Walker M, Gill N, Askew C (2011) Effect of cold water immersion on repeated cycling performance and limb blood flow. British Journal of Sports Medicine 45: 825-829
54. Versey N, Halson S, Dawson B (2011) Effect of contrast water therapy duration on recovery of cycling performance: a dose–response study. European Journal of Applied Physiology 111: 37-46
55. Westerblad H, Allen D, Lännergren J (2002) Muscle fatigue: lactic acid or inorganic phosphate the major cause? American Physiological Society 17: 17-21