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Active Recovery vs. Cold Water Immersion with Neoprene for Exercise Recovery

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ACTIVE RECOVERY VS. COLD WATER IMMERSION WITH NEOPRENE FOR EXERCISE RECOVERY

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CERTIFICATE OF APPROVAL

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MASTER OF SCIENCE THESIS

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This is to certify that the Thesis of

Edward Mussi Jr.

submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of

Health Sciences and Human Performance
at Ithaca College has been approved.

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ABSTRACT

Purpose: Active recovery (AR) and cold-water immersion (CWI) are currently the gold standards for intermittent exercise recovery and recovery across days, respectively. The localized cooling of cold water immersion inhibits its beneficial effects during intermittent recovery by decreasing power. Cold water immersion wearing a lower body neoprene suit (CWIN), however, reduces localized cooling and may potentiate beneficial effects, perhaps making CWI useful for intermittent recovery. Therefore, this project compared the effects of AR and CWIN on repeated sprint cycling performance.

Methods: Ten physically active individuals volunteered to participate in the study; their mean and SD for age, height and weight were: 25 (5.1 y), 173 (8.6 cm), and 76 (11.6 kg). Subjects performed the testing protocol on two occasions [(treatment (CWIN) and control (AR)] separated by seven days in a randomized crossover design. Each lab visit, the subjects completed three 30 s Wingate sprints with 7.5% of their bodyweight as resistance interspersed with four min of light cycling (60 rpm 1 kg). The first Wingate sprint test was baseline and the following two were used to cause fatigue. Subjects then completed a 5 min passive recovery, 12 min recovery modality (CWIN or AR), and another 5 min passive recovery. After the 22 min recovery period, subjects performed a fourth 30 s Wingate sprint. Across sprints one and four power output, blood lactate, temperature, rating of perceived recovery, and heart rate were compared using repeated measures ANOVAs. **Results:** There was no significant difference between CWIN and AR for power (peak and mean), lactate, temperature, and rating of perceived recovery. Heart rate was significantly lower with CWIN ($F_{(1,9)} = 45.424$, $p < 0.001$, $\eta_p^2 = .835$). Peak power was significantly lower from Wingate 1 to Wingate 4 with AR (-6.20%, $p <$

0.05). **Conclusion:** The findings show that neither CWIN nor AR is a superior recovery modality for physically active individuals, however CWIN alleviated traditional CWI intermittent power deficits.

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DEDICATION

This thesis is dedicated to my parents and Pop.

To my parents, who have supported me and pushed me onwards and upwards continuously throughout the years; none of this would have been possible without your love and kindness. Thank you!

To Pop, who kindled in me the unquenchable desire for edification. Safe flying, Ace.

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INTRODUCTION

Many sports require repeated bouts of sprinting. Each subsequent sprint bout increases physiological and perceptual strain (Serrano, Salvador, González-Bono, Sanchís, & Suay, 2001). A failure to recover between bouts of exercise negatively impacts intermittent performance (Karlsson, Bonde-Petersen, Henriksson & Knuttgen, 1975). Therefore, optimal recovery between bouts is essential. Intermittent recovery is inversely related to muscle fatigue. Muscle fatigue, for the purposes of this paper, is defined as an acute deficit of performance, lasting under one hour, that includes increased perceived effort and reduced strength (Debold, Fitts, Sundberg, & Nosek, 2016; Fitts, 2016; Kent, Ørtenblad, Hogan, Poole, & Musch, 2016; Poole, Burnley, Vanhatalo, Rossiter, & Jones 2016; Westerblad, 2016).

To combat fatigue, many modalities are used to enhance recovery. Popular forms include active recovery, massage, electrical muscle stimulation, and stretching. However, only active recovery improves intermittent recovery, as it promotes increased blood flow through low intensity activity (Bleakley et al., 2012; Malone, Blake, & Caulfield, 2014; Nédélec et al., 2012; Peterson et al., 2015; White & Wells, 2015). Increased blood flow potentiates pH restoration by carrying lactate, accumulated during exercise, to the liver, heart, and skeletal muscle for oxidation or gluconeogenesis (Mota et al., 2017; Sökmen, Witchey, Adams, & Beam, 2018). Reduced lactate levels are associated with improved recovery and performance, making active recovery the gold standard for intermittent recovery (Mota et al., 2017; Sökmen et al., 2018; White & Wells, 2015).

One possible modality for intermittent exercise recover that is not used is cold water immersion (CWI), which improves recovery across days to enhance power (Ihsan, Watson, & Abbiss, 2016; Ingram, Dawson, Goodman, Wallman, & Beilby, 2009; Leeder, Gissane, van Someren, Gregson, & Howatson, 2012). The benefits of CWI are attributed to temperature, pressure, and buoyancy mediated effects (Ihsan et al., 2016). These three factors impact a chain of physiological events that lead to improved post-exercise recovery by decreasing secondary exercise-induced muscle damage, cardiovascular strain, and central nervous system fatigue, while concurrently increasing parasympathetic activity (Ihsan et al., 2016). However, CWI has negative short-term effects, which limit its practicality for use during or in-between athletic events. Rapid and prolonged bodily cooling causes extreme thermal distress, inhibits muscle contractility, and limits metabolite efflux, thereby decreasing power output (Abramson et al., 1966; Crowe, O'Connor, & Rudd, 2007; Fitts, 1994; Ihsan et al., 2016; Lloyd, 1994).

Despite the volume of research on CWI, no investigation has yet reported a way to decrease its adverse effects while maintaining its beneficial properties. Hayward and French (1989) reported that staged entry (30 s to waist then full immersion) reduced an individual's accelerated respiratory frequency caused by cooling, but did not address overall thermal discomfort. Expectations of thermal distress may lead to decreased compliance and, although shorter duration immersions may attenuate this issue, they may also decrease fluid dynamic and cooling benefits (Crowe et al., 2007; Johnson, Branch, & McMenemy, 1989; Versey, Halson, & Dawson, 2013). To reduce negative effects with CWI, some have tried full neoprene wetsuits (Allan, Elliott, & Hayes, 1986; Castagna, Blatteau, Vallee, Schmid, & Regnard, 2013; Grahn, Dillon, & Heller, 2009; Wolff, Coleshaw, Newstead, & Keatinge, 1985). Although wetsuits decrease thermal distress and respiratory frequency while increasing pressure and buoyancy mediated effects, they also interfere with beneficial thermoregulatory properties needed for recovery (Allan et al., 1986; Castagna et al., 2013; Grahn et al., 2009; Wolff et al., 1985). Wakabayashi, Kaneda, Sato, Tochihara, and Nomura (2008) combined the previously mentioned approaches utilizing lower body neoprene. They found it reduced thermal discomfort while allowing substantial cooling in the uncovered areas; however, performance recovery was untested.

No investigations have compared the effectiveness of active recovery to CWI with lower body compressive neoprene to mitigate the initial neuromuscular power decrease, and metabolite efflux, and thermal discomfort while maintaining all the benefits. Theoretically, wearing compressive neoprene on only the lower body while fully emerged (shoulder depth) in cold water may cause an intra-biological thermal contrast gradient and subsequent diffusion to occur. The neoprene provides protective insulation from the waist down creating additional upward thrust (Cordain & Kopriva, 1991). Once fully immersed, cardiac output and stroke volume increases and the difference in pressures may force cold blood to circulate in the vasodilated limbs, slightly cooling the locomotive muscles while returning warm blood to the trunk, thereby mitigating extensive core cooling (Park, Choi, & Park, 1999). This phenomenon may allow the beneficial cooling properties to impact the locomotive aspects of the lower extremities with lessened power deficits, decreased thermal and respiratory distress, and accelerated metabolite efflux.

Statement of Purpose

The purpose of this study was to determine if partial neoprene coverage with CWI alleviates traditional negative short-term power effects, while improving performance across work bouts relative to active recovery.

Hypotheses

The hypotheses in this study were:

1. Wearing lower body neoprene during cold water immersion will significantly help maintain peak power, mean power, and percentage decrease in power compared to active recovery between bouts of exercise.
2. There would be no difference in blood lactate between the two recovery modalities.

Assumptions of the Study

The following assumptions were made with regards to this study.

1. Subjects abided by the pre-test instructions (Appendix B).
2. Subjects exerted maximal effort in all Wingate protocols.
3. Subjects were fully recovered prior to the second testing session.

Definition of Terms

For the purposes of this study the following terms were defined operationally.

1. Intermittent recovery. The recovery period between bouts of exercise in the same session.
2. Cold water immersion (CWI). A recovery modality following a period of exercise in which a substantial part of a human body is immersed in a bath of 50-59 degrees Fahrenheit (°F) water for a limited duration.
3. Passive recovery (PR). Stillness and inactivity during a recovery period.

4. Active Recovery (AR). Exercising during a recovery period with a diminished intensity immediately after a bout of exercise.
5. Peak power (PP). Maximum power obtained averaged over 5 s during a Wingate test.
6. Mean Power (MP). Average power obtained during a Wingate test.
7. Percentage decrease in power ($\%_{dec}$). Magnitude of power loss expressed in a percentage, from peak to minimum, which occurred during a Wingate test.
8. Excitation contraction-coupling (ECC). Entire sequence of reactions linking the excitation of plasma membrane to activation of contraction in skeletal muscle.
9. Blood lactate (BLA). The final byproduct of anaerobic glycolysis which accumulates in the body with sustained high intensities.
10. Rating of perceived recovery (RPR). A categorical self-assessment of recuperation after exercise.
11. Fat-free mass (FFM). Mass of an individual's internal organs, bone, muscle, water, and connective tissue.
12. Core temperature. Degree of heat internally generated, usually maintained in proximity to 98.6 degrees Fahrenheit (°F).

Delimitations

1. Physically active college-aged males from Ithaca College were used as subjects.
2. A cycling Wingate test was used for power calculation.
3. A wetsuit thickness of 7 mm, shoe thickness of 5 mm, duration of 12 min, and water temperature of 59° F were used for cold water immersion with neoprene.
4. Active recovery consisted of stationary cycling with 1 kg of resistance at 80 rpm for a duration of 12 min.

5. A tympanic thermometer, blood lactate analyzer, modified Borg rating of perceived recovery scale, Polar chest heart rate monitor, and SIM power software were used as measurement tools.

Limitations

1. Results may not be generalizable to people outside the targeted age range or demographic.
2. Results may not be generalizable to other exercise modalities.
3. Results may not be generalizable to times outside of the experimental time-frame.
4. Physiological findings may not be generalizable to other physiological variables.
5. Results may not be generalizable to other environments, including different active recovery methods and different CWI temperatures.

Chapter 2

REVIEW OF LITERATURE

This review provides a detailed description of the different physiological fatigue and cardiovascular mechanisms and thermally induced psychological modifications that occur during and after cold water immersion (CWI) to improve intermittent recovery. Included is research into the following areas: Fatigue including acidosis and phosphorylation and central and peripheral fatigue, modalities for intermittent recovery, fatigue reduction with CWI including cardiovascular enhancement, metabolites, heat transfer, central nervous system fatigue, and psychological and perceptual improvements, and finally thermal discomfort with CWI.

Skeletal Muscle Fatigue

As related to sprint performance, skeletal muscle fatigue is reflected by decreased force and increased perceived effort that results in lower performance (Joyner, 2016). Muscle fatigue can be described as central (within nervous system), peripheral (within muscles), or global (combined) fatigue (Poole et al., 2016). The main reasons muscle fatigue is believed to occur during sprinting is the contemporaneous increase of acidosis and phosphorylation and the decrease of central and peripheral neuromuscular activation (Debold et al., 2016; Fitts, 2016; Nybo & Nielsen, 2001; Poole et al., 2016; Westerblad, 2016).

Acidosis and Phosphorylation. Acute skeletal muscle fatigue develops in situations with high energy demand, such as sprinting, which is largely dependent on anaerobic metabolism (Fitts, 2016). In particular, two end products of anaerobic metabolism, hydrogen ions (H^+) and inorganic phosphate (P_i), are believed to play a role in skeletal muscle fatigue. The increase in H^+ reduces intracellular pH creating acidosis, while P_i increases the phosphorylation of myosin regulatory light chains concurrently accelerating myosin actin detachment (Debold et al., 2016; Fitts, 2016; Westerblad, 2016). The excess H^+ slows the rate of ADP release from myosin decreasing overall cross-bridge cycling speed and therefore, shortening velocity (Debold et al., 2016). Furthermore, increases in P_i leads to myosin light chain phosphorylation, thereby amplifying the decreased shortening velocity and as a result, peak power falls by 70% (Fitts, 2016).

Central and Peripheral Fatigue. High-intensity anaerobic exercise requires neuromuscular activation. Central and peripheral activation facilitates neuromuscular activation. The location of the stimulation, either within the CNS or motor units, distinguishes whether the activation of the muscle is central or peripheral. The physiological factors contributing to neuromuscular fatigue are unknown at this time, but may be affected by the gradual increase in core body temperature (hyperthermia) associated with exercise (Nybo & Nielsen, 2001; Poole et al., 2016).

Exercise-induced hyperthermia describes the progressive rise in body temperature. Hyperthermia is associated with a reduced force production due to decreased voluntary activation and neural drive to the muscles (i.e., central fatigue) (Nybo & Nielsen, 2001; Taylor, Todd, & Gandevia, 2006). Reduced neural drive and other neuromuscular changes lower the calcium response and therefore negatively effect excitation-contraction coupling (ECC), which decreases muscle function and results in fatigue (Kent et al., 2016). Overall, acidosis and phosphorylation, along with decreased central and peripheral neuromuscular activation due to heat, creates fatigue. Fatigue, therefore, inhibits an individual's ability to contract muscles maximally, reducing performance because it limits cross-bridge force, myofibril velocity, and therefore power as discussed in peripheral fatigue (Nybo & Nielsen, 2001).

Modalities for Intermittent Recovery

Achieving an appropriate balance between exercise and recovery is important to maximizing performance. Recovery modalities are techniques that increase the rate and quality of recovery allowing athletes to consistently train and compete at optimal levels. Many different modalities are used to improve intermittent fatigue recovery, including massage, electrical muscle stimulation, static stretching, active recovery (AR) and CWI, but only AR is known to reduce fatigue (Malone et al., 2014; Nédélec et al., 2012; Peterson et al., 2015). Each modality has been widely tested; for brevity, a single example of each follows.

Robertson, Watt, and Galloway (2004) found that leg massage between work bouts did not lower blood lactate concentration (p = 0.82) and heart rate (p = 0.81), or improve max power (p = 0.75) and mean power (p = 0.66). Consequently, massage did not improve performance relative to passive fatigue recovery. As with massage, stretching also did not improve performance. In another study, static stretching for 30 s in-between work bouts did not improve leg power relative to passive recovery (Yamaguchi & Ishii, 2005). In the case of electrical stimulation, Malone, Coughlan, Crowe, Gissane, & Caulfield (2012) investigated performance parameters in trained triathletes (N = 16) after short term recovery from supramaximal bouts of exercise. Likewise, no significant differences between electrical stimulation, active, or passive recovery interventions for peak power (p = 0.217), mean power (p = 0.477), and fatigue index ($p = 0.234$). Electrical stimulation, therefore, was not more effective than traditional training methods for passive fatigue recovery.

On the other hand, White and Wells (2015) found AR significantly improved alpine skiing completion times ($p < 0.05$) and blood lactate concentrations ($p < 0.001$) compared to passive recovery. AR enhanced lactate removal by maintaining blood flow to fatigued muscles, thereby enhancing aerobic utilization of lactate by non-fatigued tissues. The aforementioned reduction of lactate is associated with improved recovery and performance making AR the current gold standard for intermittent recovery.

Generic water immersion is the act of submerging an individual, ranging from whole body immersion to specific body parts (limbs) in water to elicit a positive physiological and psychological response (Leeder et al., 2012). At sea level the surrounding air provides approximately 1013 pascals of equal pressure to the entire body. Water is over 800 times denser than the surrounding air and therefore exerts a greater pressure on the body than air (Wilcock, Cronin, & Hing, 2006). This pressure is called hydrostatic pressure and it is equal to: $P = Patm + g \bullet \rho \bullet h$, where; Patm = 1013 Pa, g = 9.81 m/s^2, ρ = water density 1000 kg/m^3, h = height of the water. The deeper a person is submerged, the more pressure will act upon them. Consequently, the increased pressure will provide a greater physiological effect at full immersion (i.e., shoulder depth) (Wilcock et al., 2006).

In the case of CWI, Dixon and associates (2010) reported two primary findings when testing the power production of athletes before CWI, after CWI, and after CWI with a warm up ($N = 9$). First, cold-water exposure significantly decreased power output ($p < 0.05$). CWI cools tissues decreasing the rate of nerve transmission by reducing the production of acetylcholine at the neuromuscular junction (Abramson et al., 1966, Bleakley et al., 2012). Reduced nerve transmission may limit muscular contractile speed and therefore the force-generating ability of the muscle (Abramson et al., 1966). The second finding was that after CWI, performing a warm-up significantly improved ($p < 0.05$) power output but still slightly lower than control levels. Therefore, CWI reduces athletic performance and overall power immediately after CWI for intermittent recovery (Fitts, 1994). However, these results suggest that neuromuscular cooling is the primary cause of decreased power; reducing it may improve performance.

The negative neuromuscular cooling effects from CWI may be negated for intermittent recovery with the use of neoprene. Neoprene is an elastic fabric comprised of small closed cells filled with air, which can be manufactured as a compressive garment (wetsuit). The design gives wetsuits their insulation allowing for reduced heat exchange between the body and the surrounding environment elucidating its use for recovery during CWI (Castagna et al., 2013; Grahn et al., 2009). Theoretically, wearing neoprene only on the lower body during CWI may cause an intra-biological thermal contrast gradient. Once fully immersed, the increased cardiac output and stroke volume (discussed in detail later) and the difference in pressures, may force cold blood to circulate in the warmer limbs, cooling the locomotive muscles while returning warm blood to the trunk, mitigating extensive core cooling (Park et al., 1999). This phenomenon may allow the beneficial hydrostatic and cooling properties to reduce neuromuscular power deficits thereby lowering fatigue and improving performance.

Mechanisms of Fatigue Reduction with CWI

The following mechanisms of fatigue reduction with CWI will be discussed: Cardiovascular enhancement, metabolite clearance, heat transfer, central nervous system fatigue reduction, and psychological and perceptual improvements.

Cardiovascular Enhancement. The human body is about 60% water. As a result, during CWI, hydrostatic pressure displaces intra-biological fluids, causing a domino effect within the body that may improve recovery (Versey et al., 2013). The peripheral displacement of fluids triggers hemodilution and an increase in central venous pressure resulting in a greater central volume and circulation of blood (Stocks et al., 2004). This volume increases cardiac preload, and therefore, increases stroke volume at rest (but lower than during work), which increases cardiac output (Park et al., 1999). The cardiovascular control center interprets feedback from the baroreceptors and responds by increasing parasympathetic activity which decreases heart rate and, therefore, cardiovascular strain (Ihsan et al., 2016; Lavanga, Baselli, Fumagalli, Ristagno, & Ferrario, 2016).

Lower body neoprene may enhance CWI's ability to reduce cardiovascular strain. Castagna and colleagues (2013) studied the hydrostatic compression effect of neoprene on divers, and found the elastic pressure created from the wetsuit added to the larger main effect of hydrostatic pressure irrespective of immersion depth. CWI with neoprene, therefore, enables faster recovery and improved sense of perceptual recovery because it lowers plasma epinephrine levels and blood lactate, while increasing blood pH and arterial oxygenation (Jia, Ogawa, Miura, Ito, & Kohzuki, 2016).

Metabolite Clearance. CWI may enhance recovery by increasing metabolite clearance from muscles due to the hydrostatic pressure. During CWI, hydrostatic pressure combined with vasoconstriction from cooling causes hemodilution and blood displacement from peripheral to central regions (Stocks et al., 2004). When fluid shifts from the interstitial to the intravascular spaces, it is replaced by intracellular fluid (Stocks et al., 2004). This mechanism creates an intracellular-intravascular osmotic gradient because of the higher extracellular (intravascular) to intracellular fluid content (Ihsan et al., 2016). The osmotic gradient, therefore, increases the efflux of anaerobic metabolism's by-products by forcing them into peripheral circulation (Ihsan et al., 2016). Hausswirth and associates' (2012) study on CWI following 45 min of endurance cycling exercise in a temperate environment (20 °C) separated by 25 min of recovery interventions supports this notion. Metabolic acidosis (pH, L_a^- 1.03 ± 0.31) and dehydration (BML) were significantly reduced ($p < .05$) after the second bout of exercise compared to passive recovery (L_a^- 3.35 ± 0.44). Hausswirth and colleagues' (2012) similarly observed an increase in central blood volume, providing evidence that CWI may increase blood availability and enhance the clearance of metabolic by-products.

In contrast, cooling from CWI induces peripheral vasoconstriction that may reduce muscle blood flow, and therefore metabolite clearance. The decrease in blood flow reduces oxygen and nutrient delivery, thereby making CWI ineffective at assisting with clearance of metabolic by-products (Ihsan et al., 2016). Halson and colleagues (2008) study on CWI following cycling in the heat agrees with this theory showing it did not change lactate, glucose, pH, blood gases, catecholamines, relative to passive recovery.

One way to eliminate the negative effect of cooling induced vasoconstriction during CWI is with neoprene. Whole body neoprene wetsuits can enable thermal stabilization during CWI (Wolff et al., 1985), while partial wetsuits can prolong survival in water for an hour at five degrees Celsius (Allan et al., 1986). Wetsuit insulation provides greater protection to the tissues of the distal extremities because they lose a much higher percentage of heat than tissues within the trunk (Park et al., 1988). Although whole body wetsuits increase buoyancy and hydrostatic pressure beyond that of partial wetsuits, they decrease or eliminate any positive thermal effects (discussed in detail later). However, partial coverage neoprene may still assist with buoyancy and hydrostatic pressure mediated recovery without elimination of possible cooling benefits. Wakabayashi and associates (2008) investigated the effect of partial coverage wetsuits on thermoregulatory response. Subjects either immersed themselves in water at 29 degrees Celsius in a naked condition or water at 26 degrees Celsius wearing a partial wetsuit (covered trunk, upper arms, and thighs). Non-uniform thermal distribution consisting of higher temperatures within the trunk and lower at the distal extremities was observed in the partial wet suit group. In contrast, the naked condition exhibited uniform cooling. Tissue insulation was significantly higher with the partial wetsuit. Greater insulation of just the lower extremities will reduce vasoconstriction during CWI and may consequently increase subsequent metabolite removal, recovery, and therefore, performance.

Heat Transfer. CWI, as described by its name, involves the utilization of cold water to produce heat loss throughout the body to improve physiological and psychological recovery (Bleakley et al., 2012). Before biological recovery effects can be understood, it is important to note how heat is transferred and lost throughout the body.

When at thermal steady state, there is equal metabolic heat production and loss. CWI disrupts thermal equilibrium and heat loss begins, starting at the superficial shell (i.e., skin and then subcutaneous fat), traveling through muscle shell and eventually to the core (Rennie, 1988; Veicsteinas, Ferretti, & Rennie, 1982). Heat transfers through the body by physical conduction of the tissues and convective cooling of the blood (Rennie, 1988).

In contrast to CWI, at warmer temperatures (30-33 °C), where the body can stabilize core temperatures, the subcutaneous fat thickness is the primary insulative variable (Graham, 1988). However, with greater cold stress, adiposity's damping effects lessen, and mass and surface area become more significant insulative contributors (Graham, 1988). Muscle and subcutaneous fat account for 80% and 20% of total body insulation, respectively, which means the more muscle mass an individual has, the less heat they lose (Rennie, 1988). Pretorius, Lix, and Giesbrecht (2011) demonstrated this effect when comparing head only to body only cooling. Cooling of the head only increased heat loss by 11% more than body only cooling. When head cooling was combined with body cooling, core cooling rates increased by 39% compared to body only. This experiment demonstrated that when the head is cooled, heat loss increased within the core because of minimal protection from muscle and fat tissues. Taguchi and associates (2004) helped broaden the knowledge about insulative properties of the body, indicating that peripheral tissues provide substantial core insulation, slowing the transfer of heat.

During water immersion, sex differences impact heat transfer rates differently depending on temperature. During temperate water immersion, heat transfer is primarily based on sexual dimorphism of females regarding adipose tissue, rather than on the mass or body surface area (Graham, 1988). The higher percentage of body fat to fat-free mass (FFM) in females promotes thermal stability at mild temperatures. On the other hand, during CWI males thermoregulate easier because of a higher percentage and amount of fat-free mass (Rennie, 1988). Females cool more rapidly than males at a given cold-water temperature and immersion time (Graham, 1988). In fact, a female has to have twice the body fat percentage of a male to have a similar cooling rate under CWI conditions (Graham, 1988). However, females demonstrate less thermal sensitivity to body cooling than males by producing lower metabolic rates during CWI (Graham, 1988).

Central Nervous System Fatigue Reduction. One of CWI's primary actions on the body is to reduce peripheral and core temperatures via convective cooling (Machado et al., 2016). Reduced core temperature allows for greater heat tolerance with exercise in hot conditions before exercise hyperthermal limitations are met (>40 degrees Celsius) (Ihsan et al., 2016). CWI's ability to improve performance in heat is illustrated in the study by Peiffer, Abbiss, Watson, Nosaka, and Laursen (2010). Twenty cyclists performed two bouts of 25 min of cycling in heat separated by either 15 min of seated recovery (control) or 5 min of CWI followed by 10 min of seated recovery. During the second timed trial, power output was significantly greater and cycling time faster in CWI (327.9 ± 55.7 W) compared with control (288.0 ± 58.8 W). This outcome lead to a faster 4-km completion time for CWI [6.1 (0.3) min] compared with control [6.4 (0.5) min]. Economy and volume of oxygen uptake (VO_2) were not influenced by CWI. The researchers speculated that CWI significantly lowered rectal temperature which helped maintain endurance performance across work bouts. It must be noted that the 5 min CWI duration is relatively short and the hot environment encourages rewarming, mitigating neuromuscular cooling and subsequent power deficits. However, if used with lower body neoprene before or between exercise bouts for longer durations, the benefits may increase through improving heat storage capacity and neuromuscular recovery. Without peripheral/locomotive neuromuscular cooling deficits, an increased heat storage capacity may allow for sustained performance through maintenance of maximal voluntary contraction force post-immersion, thereby improving performance across repeated work bouts (Minett et al., 2014).

Psychological and Perceptual Improvements. CWI's ability to reduce core body temperature also leads to enhanced rating of perceived recovery (RPR) which reduces exercise-induced cerebral perturbations, positively influencing an individual's perception of overall fatigue (Ihsan et al., 2016). Three factors contribute to perceptual modification after thermal depression with CWI: 1) increased global electroencephalographic β wave activity and overall α/β wave ratio; 2) decreased dopaminergic and serotonergic system ratio; and 3) decreased activation of gravitationally-stressed postural muscles (Ihsan et al., 2016; Wilcock et al., 2006).

1) The electroencephalographic α/β ratio is calculated as an index of arousal level which strongly correlates to exercise-induced increases in temperature ($r^2 = 0.98$; $p < 0.01$), reflecting suppressed arousal (Nielsen, Hyldig, Bidstrup, González-Alonso, & Christoffersen, 2001). The strong concurrent progressive increase in α/β index of F3 (prefrontal cortex) and core temperature during exercise supports the use of the α/β index as an RPR predictor (Nybo & Nielsen, 2001). Electroencephalogram (EEG) frequency shift further supports this notion by decreasing arousal, hindering the brain's ability to sustain motor activity (Nybo & Nielsen, 2001). In other words, if the α/β index is allowed

to increase via exercise-induced hyperthermia without cooling intervention, a decreased mood state may occur, reducing an athlete's perceived recovery.

De Pauw and associates (2013) reported an increase of β3 electroencephalographic activity in Brodmann areas (BA) post-CWI after two 30 min cycling time trials in a hot environment. Electroencephalography was measured at baseline and during post-exercise recovery in BA involved in somatosensory information processing. Standardized low-resolution brain electromagnetic tomography was used to locate altered electrical neuronal activity. After time trial one, 15 min of active recovery, passive recovery, or CWI followed the first-time trial. Cycling time was significantly faster after CWI then the other conditions by approximately 4%. In contrast to CWI, which increased β3 activity in BA 13 (posterior margin of insular cortex) and BA 40 (supramarginal gyrus), active and passive recovery did not affect these variables. Consequently, the exercise in the heat decreased β activity, decreasing arousal, and therefore, performance. Since CWI decreases core temperature and enabled improved somatosensory changes in the α/β ratio, it sustains state of arousal and alertness and therefore improves RPR and performance (Nybo & Nielsen, 2001).

2) The ability of CWI to reduce core temperature also adjusts neuroendocrinological responses to the cerebral neurotransmitters dopamine (3,4-dihydroxyphenethylamine) and serotonin (5-HT; 5-hydroxytryptamine), which alters psychological/cognitive and motor functioning (Brazaitis et al., 2014; Ihsan et al., 2016). Dopaminergic and serotonergic systems influence mood state, sleep, emotion, motivation, attention, and reward (Meeusen, Watson, Hasegawa, Roelands, & Piacentini, 2006). Prolonged exercise and hyperthermia may increase serotonergic activity in the

brain (Davis, & Bailey, 1997) leading to lethargy, loss of drive, and decreased motor unit recruitment, which reduces performance (Meeusen et al., 2006). CWI reduces serotonergic activity, while increasing dopaminergic activity (Ihsan et al., 2016). Dopamine assists in the control of voluntary movement and locomotion required for normal movement patterns (Freed & Yamamoto, 1985). An increase of dopamine may improve performance via increased motivation, attention, and arousal (Meeusen et al., 2006). Therefore, as CWI increases dopamine levels and decreases the mental dampening of high serotonergic activity, the body can feel more 'awake' which improves RPR (Bleakley et al., 2012; Meeusen et al., 2006).

3) The last way in which CWI may enhance RPR depends on decreased activation of gravitationally-stressed postural muscles via buoyancy. Buoyancy is the upward force exerted by a fluid on an object placed in water based on the dispersion. The density of the object determines upward thrust. According to Cordain and Kopriva (1991), a person's body density can be calculated by the following equation:

$$D_b = M_a / (((M_a - M_w)/D_w) - RV), \text{ where:}$$

D_b = body density (g/ml) M_a = subject body mass(g)
M_w = subject underwater mass (g) D_w = water density (g/ml)
RV = residual lung volume (ml)

Human buoyancy is largely dependent on muscle (high density) and fat mass (low density). The larger proportion of fat mass to fat-free mass (FFM) in the body, the more buoyant a person will be. CWI attenuates gravitational forces on the body allowing for decreased activation of the musculoskeletal system and conservation of energy (Wilcock et al., 2006). Additionally, wearing neoprene promotes increased buoyancy because the air-filled cells provide a greater upward thrust which allows gravitationally-stressed postural muscles to relax thereby reducing perceptual fatigue and improving recovery (Cohen's effect size = 0.50–0.89) (Wilcock et al., 2006). Subjects with a higher percentage of lean body mass will benefit more from wearing wetsuits because they are naturally less buoyant than subjects with more fat mass (Cordain & Kopriva, 1991).

Thermal Discomfort with CWI

The use of CWI for intermittent recovery comes with one major physiological problem, extreme thermal discomfort, although the pain is decreased by the end of immersion ($p < 0.001$) (Crowe et al., 2007). Expectations of thermal distress may negatively influence the attitude and mood of a person (Johnson et al., 1989) which may theoretically lead to decreased CWI compliance. Although shorter duration immersions may improve an athlete's compliance, it decreases subsequent fluid dynamic and cooling benefits (Versey et al., 2013). Furthermore, during initial immersion, increased oxygen consumption and even hyperventilation may ensue, creating an acidotic internal environment and possible lessening of consciousness (Lloyd, 1994). Hayward and French (1989) investigated this problem and found a decrease in respiratory frequency and volume with a staged entry (30 s to waist, then full entry). A staged entry will, therefore, allow for full immersion without a substantial increase in respiration but it does not address overall thermal discomfort.

CWI may be made psychologically easier without staged entry with the use of lower body neoprene (Wakabayashi et al., 2008). Neoprene reduces heat exchange between the body and water. The partial insulation might lead to a greater esophageal and subsequent core temperature and might help address the issue of initial thermal distress during CWI. Additionally, Wakabayashi and colleagues (2008) found that subjects felt more comfortable during CWI while wearing partial neoprene compared to a naked condition. Therefore, lower body neoprene may decrease the negative psychological thermal impact and ensuing hyperventilation of water entry by lowering initial heat exchange and creating a staged immersion with decreased entry time.

Summary

CWI with lower body neoprene may enhance the intermittent recovery of power by decreased peripheral cooling, increased parasympathetic activity, decreased central nervous system fatigue, and decreased thermal stress, while simultaneously improving RPR. Overall, athletic recovery using CWI and consequently athletic performance is a complex process not solely based on a single biological aspect. Humans are intimately interconnected by various complex mechanisms explicable only by reference to the whole. Hence, CWI's integration of psychological and physiological responses creates a holistic approach to athletic recovery with the potential of a multitude of benefits. Therefore, the purpose of this study was to investigate the differences in performance and perceived recovery after CWI with partial neoprene compared to active recovery, known as the gold standard.

Chapter 3

METHODS

The following chapter outlines the experimental design for this study. Sections on participants, procedure, recovery treatments, tests and measurements, and data analysis are presented. All procedures were approved in advance by Ithaca College's Human Subjects Review Board. A randomized repeated measures crossover design was used to determine if active recovery (AR) was more effective than cold-water immersion with lower body neoprene (CWIN) to improve performance between work bouts.

Participants

A convenience sample of ten college aged males (n = 8) and females (n = 2) from Ithaca College were recruited by flyer (Appendix A) to participate in this study; their mean and *SD* for age, height and weight were: 25 (5.1 y), 173 (8.6 cm), and 76 (11.6 kg). Prior to each testing session, subjects were sent pretest instructions and were required to wear appropriate clothing for the cycling tests (Appendix B). Each subject was made aware of the study's procedures, risks, benefits, and ability to withdraw from the study. They then completed an informed consent form before participation in the study (Appendix C), and an exercise readiness and health questionnaire (Appendix D), which were used to screen for risk factors that may limit high-intensity physical activity. Participants did not engage in any exercise the days of the testing and followed their normal diet and hydration trends. To track compliance, subjects completed a 24-hour activity and diet log (Appendix E).

Procedure

Familiarization. Figure 3.1 illustrates the sequence of testing and data collection during the study. On day 0 (familiarization) each subject arrived at the Ithaca College, Center for Health and Science. Following informed consent, subjects were weighed, measured (height, waist, hips, and inseam) and sized for lower body neoprene in order to select the proper suit size for the individual. Testing procedures and the rating of perceived recovery (RPR) scale were reviewed with each subject to maximize consistency and minimize delays during the test, for consistency. Subjects were then randomly placed into one of the two different recovery treatments. Treatment one was CWIN and treatment two was AR. Recovery treatments were assigned with a random computer generator to the subjects upon completion to eliminate subject or tester bias.

Testing. Each subject returned for testing one week after familiarization. One subject at a time performed and completed the full testing procedure before the next subject started. Resting heart rate (HR), blood lactate, and body temperature were obtained upon arrival. The subject then performed a Wingate cycle ergometer test (Appendix F). Prior to the test, subjects cycled at a self-selected pace for 5 min and performed two or three, 5 s high revolution ‘spins ups’ for a warm up. These spin ups were used to acquaint the subjects with the pedaling speed requirements of the Wingate test.

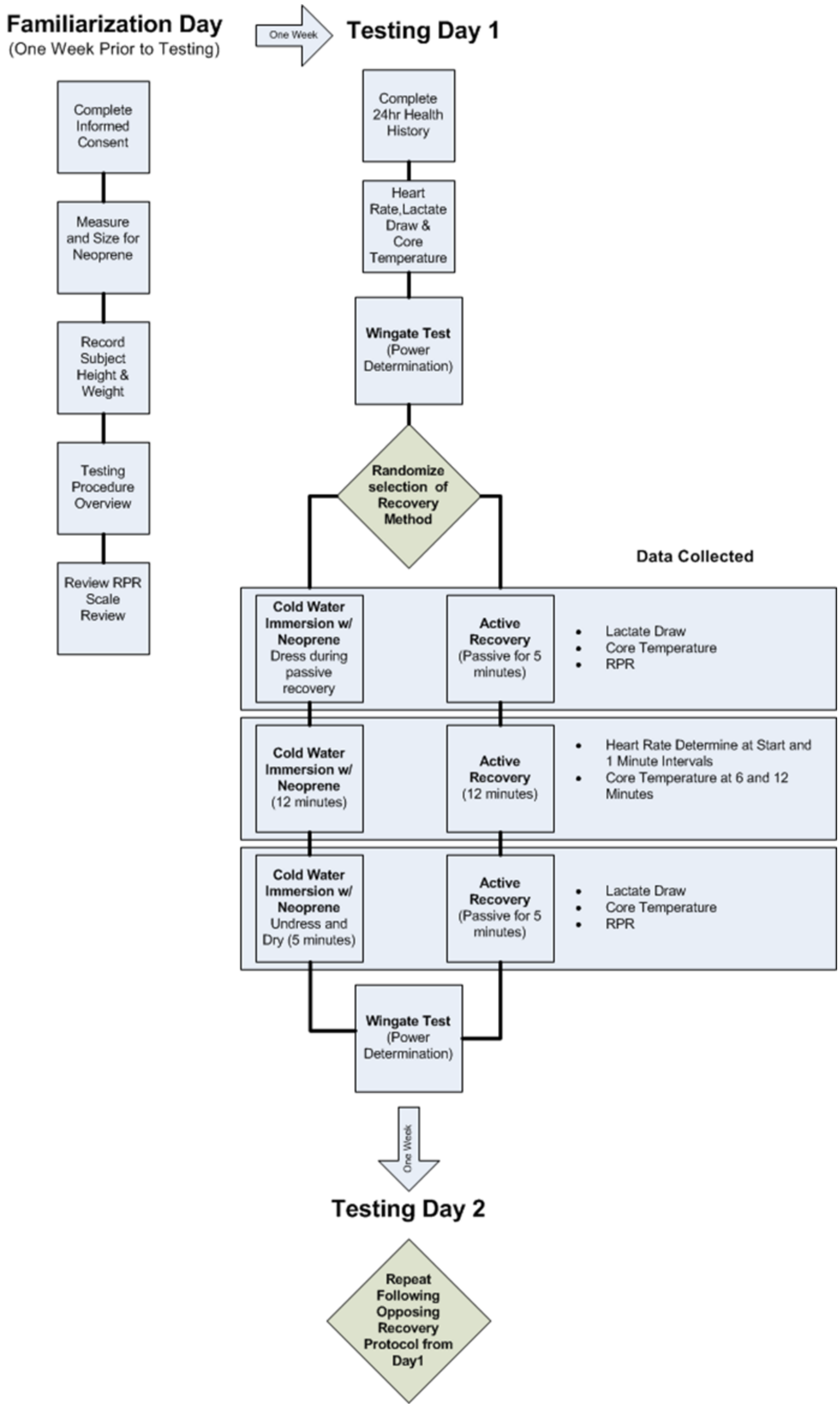

Figure 3.1. Flow Diagram of Test Procedures and Data Collection

The subjects then completed three Wingate tests consisting of 30 s work bouts on a Monark 834 E ergometer (Varberg, Sweden) against a resistance equal to 7.5% of body weight. Each Wingate test was separated by 4 min of cycling at 1 kg resistance. The ergometer was equipped with toe clips, seat height was standardized for each subject to allow for 10-15° of knee flexion, and vigorous verbal encouragement was provided for all tests. SMI Power software (Sports Medicine Industries, St. Cloud, MN), interfaced with the ergometer with an OptoSensor 2000 infrared sensor (Sports Medicine Industries, St. Cloud, MN), was used to collect data every second. The sensor was calibrated before every testing session. The following variables were measured in watts (W) during the first sprint test: peak power, mean power, and percent decrease in power. Peak power was calculated as the highest power output over any five-second interval during a sprint test. Data from the first Wingate test were used as the baseline measure. The second and third Wingate tests were used to create fatigue, whereas the fourth Wingate test was used as the post-treatment power score. The coefficient of variation for peak power, mean power, and percent decrease in power was assessed in a series of pilot studies (n = 6) and were 1.3, 1.1, and 4.6% respectively.

Immediately after the third Wingate test, a 5 min passive recovery period began to allow for a lactate draw, temperature recording, RPR assessment, and a change of clothing. The 5 min period allowed blood lactate levels to peak while providing time for changing clothing (Goodwin, Harris, Hernández, & Gladden, 2007). The recovery period lasted 12 min. HR was collected at the start of the recovery modality and every minute during recovery. Temperature was taken prior to the recovery period, at 6 min and 12 min during recovery, and immediately prior to the fourth Wingate test. After completing the

12 min recovery, subjects were allowed 5 min to dry off and change clothing, or wait passively standing. A third lactate draw was performed and RPR was obtained during the 5 min drying and changing time. The subjects then immediately completed the Wingate protocol a fourth time for comparison.

One week later the subjects repeated the entire testing protocol with the other recovery treatment. Three means of assessing recovery were used to provide a holistic view of recovery: physical performance, physiological, and psychological. Body temperature, heart rate, and lactate levels were the physiological measures; rating of perceived recovery (RPR) was the psychological measure; and ergometer power was the performance measure.

Tests and Measurements

Active Recovery. The subject waited 5 min standing. The subject then cycled at 60 rpm with 1 kg of resistance for 12 min (Ohya, Yamanaka, Ohnuma, Hagiwara, & Suzuki, 2016) and waited 5 min standing, during which, they gave the tester their RPR.

Cold Water Immersion with Neoprene. The subject had 5 min to put on the seven-millimeter-thick lower body neoprene suit including shoes. The subject then sat in a tub at 15 °C for 12 min at shoulder level and had 5 min to dry off, dress, report their RPR, and return to the bike.

Lactate Draw. A droplet blood sample was taken at rest, 5 min after completing the first Wingate, and 5 min after the recovery protocol to determine blood lactate measures. Lactate was analyzed using a Lactate Plus Meter (Waltham, MA) Each time the subject’s fingertip was sterilized using an alcohol prep pad. A new sterile lancet was used to puncture each subject's finger so that a blood sample could be obtained to analyze blood lactate. Guidelines are listed in Appendix G.

Heart Rate. HR was collected at rest, at the start of the recovery modality, and every minute during recovery. HR was collected using a Polar H10 HR monitor (Kempele, Finland) and EliteHRV smartphone application through Bluetooth smart technology, and coded 5 kHz transmission. The Polar H10 HR monitor is fully waterproof and can transmit data while submerged. Perrotta, Jeklin, Hives, Meanwell, and Warburton (2017) reported on the validity ($r = 0.92$; $p < 0.0001$; confidence interval 95% = 0.90-0.93) of this application to collect and analyze HRV and HR data.

Body temperature. Body temperature was taken at rest, immediately before the recovery period, at 6 min and 12 min during recovery, and right before the last Wingate test. Temperature was taken with a Braun infrared ear thermometer (Kronberg im Taunus, Germany). Chamberlain and associates (1995) confirmed the accuracy of an infrared ear thermometer without using corrective offsets to estimate temperature. Kamada, Miyamoto, Yamakage, Tsujiguchi, and Namiki (1999) confirmed the validity for using the Braun thermometer when rectal temperature monitoring is unreliable ($r = 0.72\text{-}0.79$, $p < 0.01$).

Rating of Perceived Recovery. The subject's rating of perceived recovery was collected during both 5 min passive recovery periods. The RPR was collected using the CR-10 scale for lower extremity to assess pain and fatigue levels (Appendix H). Subjects select a number from zero to ten to represent their level of recovery. Zero represents no recovery at all and ten represents complete recovery. Chen, Fan, and Moe (2002) reported on the validity and reliability of the CR-10 scale.

Data Analyses

Data were analyzed using IBM SPSS 22 for Windows. The variables were checked for normality and sufficient evidence of a normal distribution. Repeated measures ANOVAs were run for all dependent variables to asses if CWIN was different than AR. Mauchly's test was performed to check for violations of the sphericity assumption. If Mauchly's test was found to be significant, Greenhouse-Geisser corrected degrees of freedom were reported. Effects sizes represented by η^2 (Eta squared) were reported to provide an indication of the magnitude of difference between the two experimental conditions. Alpha level of 0.05 was set for all statistical tests.

Chapter 4

RESULTS

In the present study the effects of utilizing partial neoprene coverage during CWI (CWIN) for intermittent recovery were assessed in a randomized, crossover-controlled, experimental design. Statistical analyses were performed for both conditions, as well as each dependent variable. Dependent variables were assessed at the time points of Baseline, Wingate 1 (W1), during both CWIN and active recovery (AR) conditions, and Wingate 4 (W4). The results of this analysis are described and represented in tables and figures below which are organized into subsection by dependent variable type. The performance variables were peak power (PP), mean power (MP), and percentage decrease in power (%D). The physiological variables were lactate (La), temperature (Tem), heart rate (HR), and average heart rate during recovery (aveHR). The psychological variable was rating of perceived recovery (RPR).

Performance Measures

Descriptive statistics for PP, MP, and %D are found in Table 4.1. A 2x2 repeated measures ANOVA revealed no significant Condition x Time interaction effect for PP. However, the 2x2 ANOVA revealed a significant main effect for time ($F_{(1,9)} = 15.651$, $p < 0.05$, $\eta_p^2 = 0.635$). Post hoc paired sample *t*-test analyses revealed a significant decrease in PP between W1 and W4 for AR (-6.20%; $t = 3.162$, $p < 0.05$, $df = 9$) (Figure 4.1). PP was not significantly different from W1 to W4 with CWIN (-2.50%).

A 2x2 repeated measures ANOVA revealed no significant Condition x Time interaction effect for MP (CWIN = -2.30%; AR = -5.22%) or main effect for MP (Table 4.1).

A 2x2 repeated measures ANOVA revealed no significant Condition x Time interaction effect for %D (CWIN = 2.10%; AR = -4.90%) or main effect for %D (Table 4.1).

Table 4.1.
Descriptive Data for Peak Power (PP), Mean Power (MP), and Percent Decrease in Power (% D) for Wingate 1 (Baseline) and Wingate 4 (Recovery).

	CWIN (*N* = 10) *M (SD)*	AR (*N* = 10) *M (SD)*
Baseline PP	839.40 (181.14)	841.00 (184.80)
Recovery PP	825.80 (219.57)	787.10 (168.98)
Baseline MP	603.50 (119.12)	619.00 (127.94)
Recovery MP	591.60 (130.28)	586.70 (110.53)
% D Wingate 1	-50.34 (8.07)	-48.72 (7.68)
% D Wingate 4	-51.03 (9.10)	-46.26 (9.21)

Note: There were no significant differences between groups. All units measured in Watts.

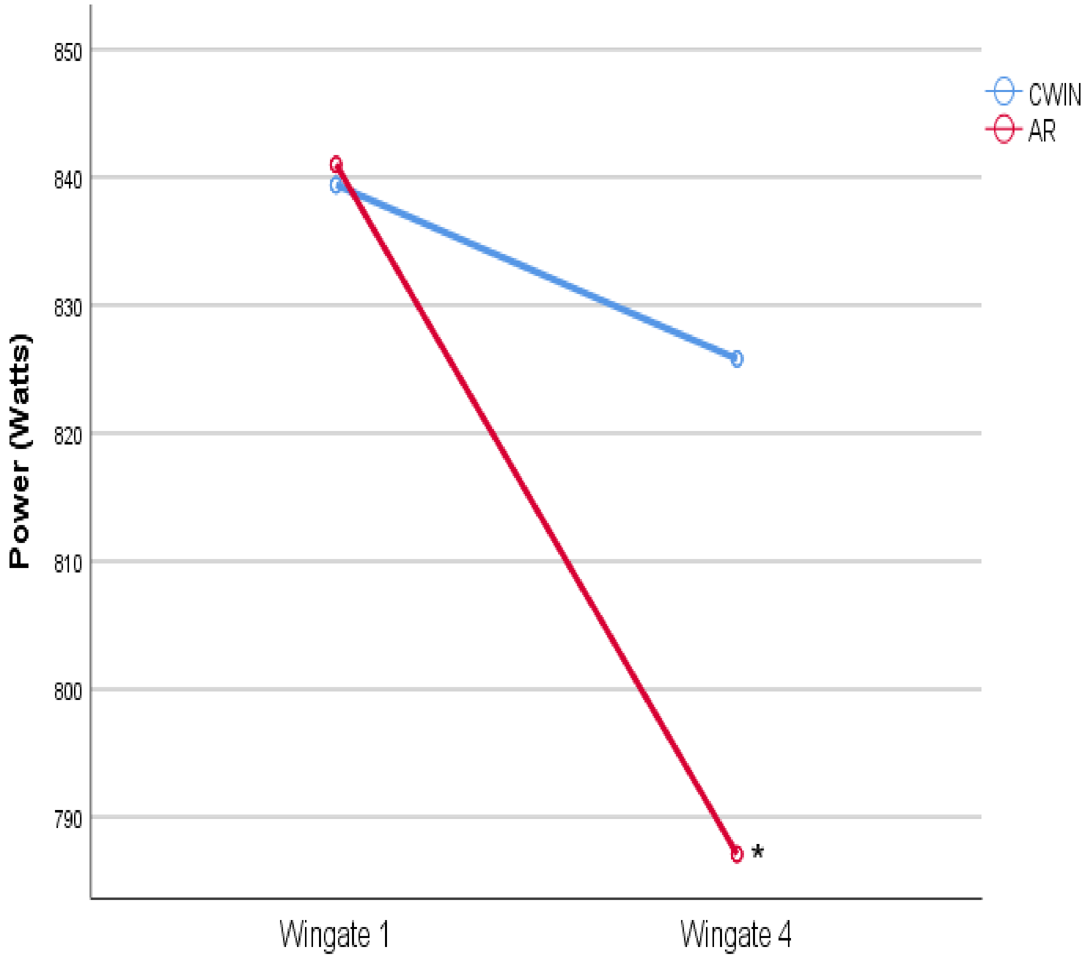

Figure 4.1. Line graph showing peak power (PP) change from Wingate 1 (W1) to Wingate 4 (W4). * PP significantly decreased between W1 and W4 for active recovery ($t = 3.162$, $p < 0.05$, $df = 9$). PP was not significantly different between modalities or between W1 and W4 for CWIN.

Physiological Measures

Lactate. Descriptive statistics for La are found in Table 4.2. A 3x2 repeated measures ANOVA revealed no significant Condition x Time interaction effect. However, the 3x2 ANOVA revealed a significant main effect for time between all La measures ($p < 0.001$, $p < 0.001$, and $p < 0.001$, respectively). Mauchly's Test of Sphericity was significant for the main effect ($W = 0.402$, $\chi^2 (9) = 7.286$, $p < 0.05$); the Greenhouse-Geisser correction was then employed using $\varepsilon = 0.679$.

Temperature. Descriptive statistics for Tem are found in Table 4.3. A 5x2 repeated measures ANOVA revealed no significant Condition x Time interaction effect. However, the 5x2 ANOVA revealed a significant main effect for time between Tem 3 and 5 ($p < 0.05$) and Tem 4 and 5 ($p < 0.05$). Mauchly's Test of Sphericity was significant for the main effect ($W = 0.049$, $\chi^2 (9) = 22.409$, $p < 0.05$); the Greenhouse-Geisser correction was then employed using $\varepsilon = 0.496$. Additionally, a post hoc paired sample *t*-test showed Tem was significantly higher after W3 prior to CWIN ($t = -4.436$, $p < 0.05$, $df = 9$).

Heart Rate. Descriptive statistics for HR and aveHR are found in Table 4.4. A 2x2 repeated measures ANOVA revealed a significant Condition x Time interaction effect for HR ($F_{(1,9)} = 45.424$, $p < 0.001$, $\eta_p^2 = 0.835$). The 2x2 ANOVA also revealed a significant main effect for condition and time ($F_{(1,9)} = 14.148$, $p < 0.05$, $\eta_p^2 = 0.611$; $F_{(1,9)} = 219.641$, $p < 0.001$, $\eta_p^2 = 0.961$ respectively). Additionally, a paired sample *t*-test showed AveHR was significantly lower ($t = -7.327$, $p < 0.001$, $df = 9$) during CWIN than AR (Figure 4.2).

Table 4.2.

Descriptive Data for Blood Lactate Baseline (Lactate 1), Prior to Recovery (Lactate 2), and After Recovery (Lactate 3)

	CWIN (N = 10) *M (SD)*	AR (N = 10) *M (SD)*
Lactate 1	1.52 (0.53)	2.12 (1.65)
Lactate 2	15.20 (2.12) **	15.68 (1.89) **
Lactate 3	10.34 (2.30) **	9.79 (2.05) **

Note: Blood lactate (La) 2 prior to recovery was significantly higher than La 1 (** $p < 0.001$). After recovery La 3 was significantly lower than La 2 (** $p < 0.001$); but still significantly higher than baseline La 1 (** $p < 0.001$). All units measured in mmol/litre.

Table 4.3.

Descriptive Data for Temperature Baseline (Temperature 1), Prior to Recovery (Temperature 2), Six Minutes of Recovery (Temperature 3), Twelve Minutes of Recovery (Temperature 4), and Prior to Wingate Four (Temperature 5)

	CWIN (N = 10) *M (SD)*	AR (N = 10) *M (SD)*
Temperature 1	97.87 (0.73)	98.06 (0.63)
Temperature 2	98.72 (0.66) *	98.21 (0.89)
Temperature 3 $^{+}$	98.68 (1.09)	98.18 (0.89)
Temperature 4 $^{+}$	98.65 (1.18)	98.17 (1.01)
Temperature 5	98.22 (0.86)	97.96 (1.01)

Note: $^{+}$ Main effect for time between Tem 3 and 5 (p < 0.05) and Tem 4 and Tem 5 (p < 0.05). Prior to recovery, Tem 2 was significantly higher than Tem 1 for CWIN (* $p < 0.05$). Temperature was not significantly different at any other time point or between modalities. All units measured in degrees Fahrenheit.

Table 4.4.
Descriptive Data for Heart Rate at Rest (HR 1), After Recovery (HR 2), and Average Heart Rate throughout Recovery (AveHR)

	CWIN (N = 10) *M (SD)*	AR (N = 10) *M (SD)*
HR 1	76.00 (13.29)	74.70 (12.24)
HR 2	103.40 (7.44) * ++	134.90 (15.95) *
AveHR	106.22 (7.67) **	135.50 (17.12)

Note: HR 2 after recovery was significantly higher than HR 1 at rest for CWIN and AR (* $p < 0.05$). AveHR throughout recovery was significantly lower for CWIN than AR (** $p < 0.001$). HR 2 after recovery was significantly lower for CWIN than AR (++ $p < 0.001$). All units measured in beats per minute.

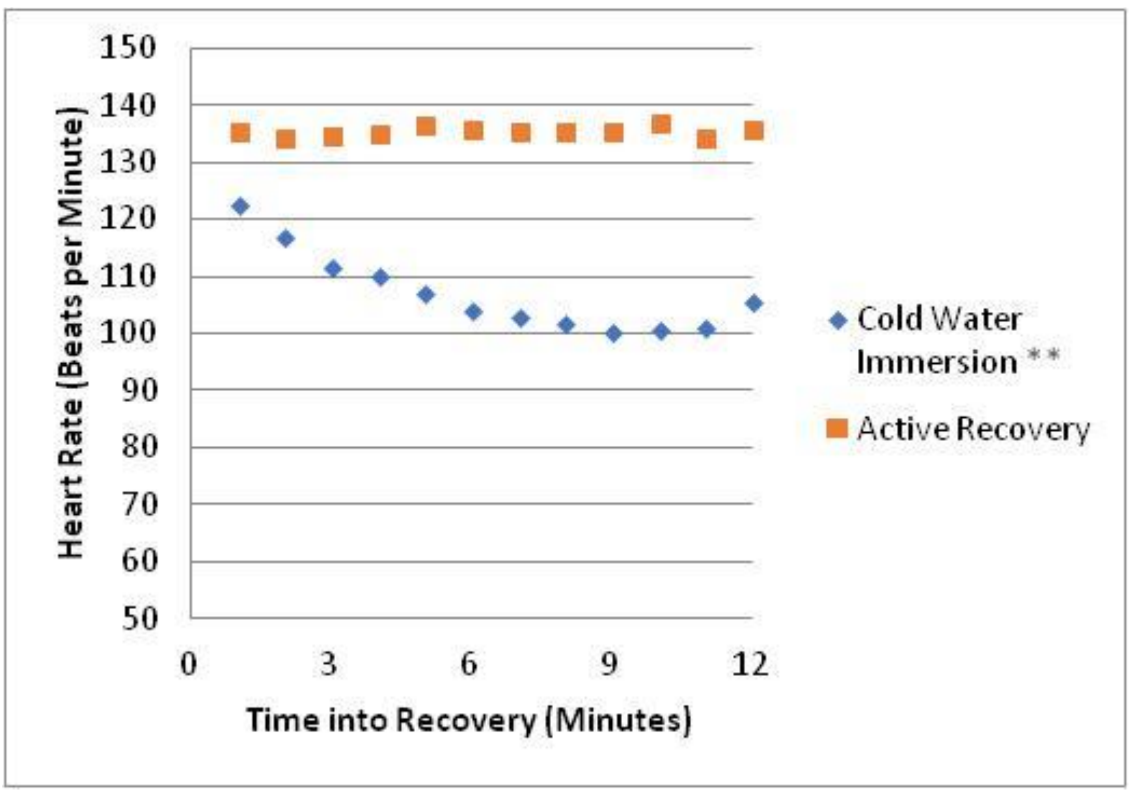

Figure 4.2. Heart Rate Every Minute During Recovery; Average Heart Rate (** $p < 0.001$)

Psychological Measure

Rating of Perceived Recovery. After W3 and recovery, subjects were asked to rate their perceived amount of recovery on a Likert scale of 0-10, with 10 being fully recovered and 0 being no recovery. Descriptive statistics for RPR are found in Table 4.5. A 2x2 repeated measures ANOVA revealed no significant Condition x Time interaction effect. However, the 2x2 ANOVA revealed a significant main effect for time ($F_{(1,9)}$ = 149.397, $p < 0.05$, $\eta_p^2 = 0.947$).

Table 4.5.
Descriptive Data of Ratings of Perceived Recovery Pre and Post-Recovery Modality

	CWIN (N = 10) *M (SD)*	AR (N = 10) *M (SD)*
Pre-Recovery (RPR 1)	1.95 (1.19)	1.55 (1.52)
Post Recovery (RPR 2)	6.10 (1.91) *	5.55 (1.85) *

Note: RPR post recovery modality were significantly lower than pre-recovery measures with CWIN and AR (* $p < 0.001$). All units measure on a 0-10 scale.

Summary

PP was significantly decreased from W1 to W4 with AR ($p < 0.05$) and not significantly different with CWIN. PP and MP were greater for CWIN than AR, but the difference did not reach statistical significance likely due to large amounts of variability in the measure. HR throughout recovery and after recovery was significantly lower for CWIN than AR ($p < 0.001$ and $p < 0.001$ respectively). La, Tem, and RPR were not significantly different between modalities.

Chapter 5

DISCUSSION

The purpose of this study was to determine if partial neoprene coverage with CWI (CWIN) alleviates traditional CWI's negative short-term power effects and possibly improves performance across work bouts relative to active recovery (AR). This study was the first to use neoprene with CWI between bouts of exercise to mitigate the initial decrease in neuromuscular power and metabolite efflux. There were two hypotheses: First, CWIN would significantly help maintain PP, MP, and percent decrease in power during the Wingate compared to AR between bouts of exercise. Second, there would be no difference in blood lactate between the two recovery modalities. The results indicate that during intermittent recovery, CWIN helped maintain performance and positively impacted lactate removal equal to AR suggesting that both modalities are equally effective for intermittent recovery between sprint bouts.

CWIN vs. AR

Results reveal significantly reduced PP (6.2%) and a non-significant reduction in MP (4.4%) from W1 to W4 with AR, while CWIN elicited a non-significant difference in both (2.5% and 2.3% respectively). The results for AR are consistent with previous studies (Sökmen et al., 2018; Wahl et al., 2013). The two-way interaction plot (Figure 4.1) shows diverging lines indicating a significant interaction effect for PP between CWIN and AR, albeit these findings were statistically non-significant with a *p*-value of 0.19 and power of 0.25. Non-significance likely occurred because of high variability in athleticism of the subject population and data. Additionally, a power analysis revealed that a sample size of about 68 subjects, assuming similar findings, was needed to improve power sufficiently to show statistical significance.

Lactate was significantly reduced following recovery and not statistically different between modalities. During immersion, it is likely that hydrostatic pressure, combined with venoconstriction and the increased venous return from neoprene, may have caused hemodilution and blood displacement from peripheral to central regions, creating an intracellular-intravascular osmotic gradient and increasing the efflux of lactate by forcing it into peripheral circulation (Ihsan et al., 2016; Stocks et al., 2004). As initially postulated, these findings contrast with other studies of traditional CWI for intermittent recovery, perhaps in part because greater insulation of just the lower extremities maintains warmth. Reducing vasoconstriction by maintaining limb temperature, therefore, improved subsequent metabolite removal, recovery, and performance.

Results revealed that temperature was significantly lower after recovery compared to 6 min ($p < 0.05$) and 12 min ($p < 0.05$) during recovery for both modalities. This finding likely occurred because, during AR, energy is being expended maintaining warmth, and CWI has a thermal after-drop effect (Lloyd, 1994). Prior to recovery, Tem was significantly higher than baseline only for CWIN ($p < 0.05$) probably because the wetsuit was donned prior to measurement insulating and increasing core temperature. Body surface cooling resulted in a localized cooling effect represented in rectal temperature but not in other core measurement sites (Basset, Cahill, Handrigan, Ducharme, & Cheung, 2011). Therefore, infrared tympanic temperature avoided localized cooling preventing compromised validity.

Additionally, HR after recovery and average heart rate during recovery were significantly lower for CWIN than AR. Based on previous CWI studies, it is reasonable to expect that HR would decrease during immersion and remain elevated during exercise or AR (Park et al., 1999). HR response occurred as both recovery modalities continually stressed the body thermally and physically, this stress caused HR to remain significantly elevated throughout the recovery period relative to rest.

A secondary finding in the present study was that perceived recovery with both CWIN and AR was not statistically different. This finding contrasts with previous researchers who reported that shows CWI was significantly better than AR at improving RPR (De Pauw et al.,2013). Buoyancy during CWI traditionally attenuates gravitational forces on the body allowing for decreased activation of the musculoskeletal system and conservation of energy (Ihsan et al., 2016; Wilcock et al., 2006). Therefore, increasing buoyancy with neoprene should have improved relaxation of gravitationally-stressed postural muscles and reduced perceptual fatigue. Nonetheless, the lack of significance is most likely attributed to the utilization of a basic 0-10 Likert scale. A differential scale which allows test subjects to rate individual perceptual attributes (i.e., heart rate, leg fatigue, and mental fatigue) may have improved the robustness of this test.

CWIN Physiological Effects

The results of CWIN for power output in the present study contrast to those reported previously for intermittent recovery with CWI (Abramson et al., 1966; Crowe et al., 2007; Dixon et al., 2010; Fitts, 1994; Ihsan et al., 2016; Lloyd, 1994). Namely, subjects returned to within approximately 98% of baseline in PP, MP, and %D after intermittent recovery. The results in the current study most likely occurred due to the insulative properties of wearing lower-body neoprene. Dixon and associates (2010) suggested that neuromuscular cooling was the primary cause of decreased power after CWI. The neoprene reduced heat exchange between the subjects and the water mitigating lower extremity cooling; Wakabayashi and colleagues (2008) had found similar findings. The difference between CWI and CWIN is therefore an intra-biological thermal contrast (IBTC) (i.e., warm lower body and cold upper body). This phenomenon allows beneficial cooling properties to indirectly impact locomotive aspects of the lower extremities, alleviating traditional CWI's negative short-term power effects.

Traditional CWI also decreases intermittent recovery of power by limiting metabolite efflux through peripheral vasoconstriction (Halson et al., 2008; Ihsan et al., 2016). In contrast, the current data showed CWIN significantly improved lactate clearance similar to AR. As previously mentioned, insulation of just the lower extremities may have caused an IBTC gradient to occur assisting in metabolite efflux by preventing peripheral vasoconstriction and reducing HR. The lower HR during immersion increases stroke volume and heart efficiency (i.e., increased cardiac output) (Park et al., 1999). When combined with the increased hydrostatic pressure of immersion and neoprene, the difference in pressures may have forced cold blood to circulate in the warm vasodilated limbs, slightly cooling the locomotive muscles while returning warm blood to the trunk (Castagna et al., 2013). This hemodynamic effect, therefore, mitigates extensive core cooling (shown by an insignificant change in core temperature) and enables a faster recovery by accelerating metabolite efflux relative to traditional CWI (Jia et al., 2016; Park et al., 1999).

A possible confounding variable during CWIN could be the additional buoyancy of the lower extremities from the neoprene during immersion. The buoyancy caused all subjects to float supine during recovery. However, Monedero (2000) showed that a passive supine position does not improve lactate clearance compared to AR. Whereas, in the present study, CWIN and AR both significantly enhance lactate clearance and were insignificantly different from each other ($p < 0.001$ and $p < 0.001$ respectively).

Limitations and Direction for Future Research

A major methodological limitation was the lack of practicality of the CWIN group. Donning the neoprene was difficult due to the 7 mm thickness, leg graduation, and fatigue. All participants struggled and required assistance to don the neoprene. Additionally, temperature was taken after putting on the neoprene. The insulative properties of the neoprene caused Tem2 to increase and be the only significant thermal finding. Future research should explore a more practical way to create an IBTC or to easily don neoprene. Temperature should be taken before wearing neoprene in effort to capture true internal thermal expression.

A second limitation involved the decision to select a physically active population instead of an athletic one. This wide inclusion criterion allowed for easier recruitment but resulted in a large amount of between-subject variability in power outputs. The variability observed highly decreased the likelihood of detecting any significant differences with the present sample size. The measures taken to reduce variability (e.g., no eating, no caffeine, and no alcohol, etc.) may not have been stringent enough. Two subjects complained of feeling overstressed after completion of the fourth Wingate. The maximal intensity of multiple Wingate tests, combined with the criteria of only being physically active individuals – not individuals of excellent physical condition – may have led to a physiological stress their bodies were unprepared to handle. Despite the stress, no subject dropped out from the study. Recovery across days (24-48 hr) may provide a practical use for CWIN in a non-athletic population. Expectations of thermal distress during CWI may decrease compliance. Although shorter duration immersions may improve compliance, shorter durations also decrease fluid dynamic and cooling benefits (Crowe et al., 2007; Johnson et al.,1989; Versey et al., 2013). The IBTC effect of CWIN may, therefore, improve compliance by reducing thermal discomfort while maintaining traditional CWI across days beneficial properties (i.e., improved power, delayed onset muscle soreness, and RPR). Future research should consider a lengthened period of NPO (nothing by mouth) and dividing subjects by sex and athleticism.

This study contributed to the limited body of research on IBTC mitigating traditional CWI’s negative intermittent effects and for the first time subjected it to scientific analysis. The results show that CWIN is equally effective as a means of improving intermittent recovery compared to AR, although not superior. Given the findings of previous research and of the present study, investigation of IBTC and the mitigation of CWI’s negative intermittent effects should be pursued.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to determine if CWIN alleviates traditional CWI's negative short-term power effects while improving performance across work bouts relative to AR. There is evidence to support the study's hypothesis that wearing lower body neoprene during cold water immersion will significantly help maintain PP, MP, and %dec compared to AR between bouts of exercise with no difference in blood lactate. However, previous studies that generated this evidence did not utilize partial neoprene coverage for performance. Given the compressive, insulative nature of neoprene, it seemed logical to evaluate its effectiveness in promoting intermittent recovery with CWI.

Ten physically active, college-aged students, free from musculoskeletal limitations, completed a familiarization session and two experimental sessions. This study was a cross-over experimental design in which PP, MP, %D, La, Tem, HR, and RPR measures were obtained. A series of repeated measures ANOVAs and paired sample *t*-tests were performed to assess main effects and interaction effects. Results revealed a significantly reduced PP ($p < 0.05$) following AR, while CWIN elicited a non-significant difference. No difference in blood lactate was found between modalities. However, during recovery, HR was the only significant interaction effect ($p < 0.001$) found. A large between-subject variability in Wingate test performance may have accounted for the minimal interaction significance. Future research should utilize a larger sample size with a more homogenous athletic population.

Conclusions

The findings of this study yield the following conclusions.

1. CWIN significantly improves the intermittent recovery of PP, MP, %D, and La between sprint bouts.
2. CWIN yields at least equal improvements to AR for the intermittent recovery of PP, MP, %D, La, and RPR between sprint bouts.

Recommendations

This study reveals the following areas of opportunity for further research on CWIN use for intermittent recovery.

1. A cross-over study comparing CWIN and CWI across days should explore whether differences between these two modalities exist.
2. Incorporate a true control group (i.e., passive recovery) to better gauge the relative effectiveness of CWIN and an AR group.
3. Incorporate measurement of R-R intervals to better assess alterations in nervous system activity during exercise and recovery.
4. Include separate thermal measurements of the lower and upper body during recovery.
5. Include additional performance measures to better gauge the generalizable effectiveness of CWIN.
6. Explore a more practical means of donning lower body neoprene and different neoprene thicknesses.
7. Utilize a larger sample size and a less variable subject population.

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APPENDIX A

Wellness Clinic Flyer

Active Recovery vs. Cold Water Immersion with Neoprene for Exercise Recovery

If you are over the age of 18, currently physically active, and can perform bicycle sprints, consider participating in my study!
I am recruiting people for a short biking study to test the difference between active recovery and cold-water immersion wearing lower body neoprene for recovery.
All subjects must be:
18-40 years old
Members of the Ithaca College community (including students, faculty, and staff)
Physically active (performs moderate intensity exercise at least 2-3x per week)
Free from musculoskeletal injuries and are physically able to participate fully
About the study:
It involves three separate days (one familiarization and two testing days) at the CHS building. The first day will consist of a walk-through of what will happen and a familiarization of the tests. This may take around 20 minutes. The following week, testing will take place. You will receive an e-mail regarding what time you are to show up to the CHS exercise physiology lab. The tests will all consist of four 30-second maximum bicycle sprint with 7.5% of your weight in resistance with either a 12-minute cycling or cold water immersion recovery period in-between. During testing, you may be subjected to, but not limited to: cold-water immersion, and finger pricks to analyze lactate accumulation, both of which may cause discomfort. The second day of testing will occur one week later and consist of the same protocol as before except with the other recovery modality. The total time commitment is around two hours. I would ask for you to maintain your current nutritional habits and abstain from exercise 48 hours in advance. There are very few risks for this study, such as a pulled muscle during bicycle sprints. If you have any questions please email me directly.
If you are willing to participate please email me to schedule your familiarization day.

Edward Mussi
emussi@ithaca.edu
Graduate Student- Exercise Physiology
Ithaca College

APPENDIX B

Pre-test Instructions

Testing date:_____________ Testing Time:_______________

You are scheduled to complete a maximum effort exercise test; your performance depends upon adherence to these instructions:

1. Do not perform heavy exercise in the 48 hours preceding your test or training.

2. Do not drink alcohol for 24 hours preceding your test or training.

3. Do not use caffeine (e.g. coffee) or nicotine (e.g. cigarettes) for three hours preceding your test or training.

4. Do not eat heavily for three hours preceding the test or training, or you may feel ill.

5. Do not eat any food that may cause you discomfort the day of the test or training.

6. Wear athletic clothing (shorts, t-shirt, and biking or running shoes are recommended).

7. Wear or bring tight fitting underwear or swim suit you can wear while in water.

Thank you for your cooperation.

APPENDIX C

Informed Consent Form

Active Recovery vs. Cold Water Immersion with Neoprene for Exercise Recovery

1. Purpose of the Study

   The purpose of this project is compare the effects of active recovery and CWI with a lower body neoprene suit on repeated sprint performance.

2. Benefits of the Study

   There is no direct benefit for you from participating in this study apart from learning the results of the study. The researcher will benefit as this will complete a class assignment. This research will increase the knowledge that exists on the use cold water immersion for intermittent recovery among a physically active population. The student conducting this research will benefit from learning how to collect scientific data and may have the potential for scholarly publication. Presentations and publication of the data will benefit the scientific community by adding to the existing literature.

   What You Will Be Asked to Do

Familiarization

Upon reporting to the CHS exercise physiology lab and being cleared to participate based on your responses to the Health History Questionnaire and 24-Hour Health Recall, you will receive and fill out the informed consent. After completing the Informed Consent, you will be measured for a neoprene suit, weighed, and familiarized and with the Wingate protocol. During this day you will also be shown rating charts that you will use to self-report perceived recovery and thermal distress/comfortability. Additionally, you will receive a list of things you should and should not do prior to arrival on testing day. You should not: perform heavy exercise 48 hours before testing, drink alcohol 24 hours before testing, consume caffeine (e.g. coffee) or nicotine (e.g. cigarettes) for three hours before testing, eat heavily for three hours before testing, and eat any food that may cause you discomfort the day of testing. You should: wear athletic clothing (shorts, t-shirt, and biking or running shoes are recommended) and wear or bring tight fitting underwear or swim suit you can wear while in water. Your total time for the familiarization-testing day is approximately 20 minutes, including set-up.

Initial______

APPENDIX C (continued)

Testing day

You will report back to the CHS exercise physiology lab and complete another 24-Hour Health Recall to ensure that you have not suffered any injuries between the familiarization day and this one. You will be fitted with a heart rate monitor and your ear

temperature will be taken. A lactate draw will then occur. During the lactate draw, an alcohol prep pad will be used to sterilize your fingertip, which will be pierced by a sterile lancet so that we can obtain a small blood sample that will be used for blood lactate analysis. You will perform three Wingate bicycle tests. You will cycle at a self-selected pace for five minutes for a warm up. You will then began cycling at 60rpm for approximately ten seconds with no weight (resistance). The test administrator will verbally count three, two, one, go. On the word “go”, the administrator will lower the test weight (7.5% of your bodyweight) on the bike and you will then begin to accelerate maximally and try to maintain maximal speed throughout the entire 30-second test. The test administrator will count down the final three seconds of the test to a verbal “stop” signal. In-between each test you will give given a four-minute period to cycle causally to recover. Upon completion of the third Wingate, five minutes will be used to allow for a second lactate draw, assess your body temperature, assess your perceived recovery, and a change of clothing. Your temperature will be taken with an ear thermometer. Perceived recovery will be assessed with a 1-10 scale. During the five-minute period, you will also put on a heart rate monitor and either remain unchanged or change into lower body neoprene including shoes. Afterwards, you will complete a 12-minute recovery. The recovery modality will be randomly assigned to you; they include active recovery and cold water immersion with lower body neoprene. Active recovery will be low intensity cycling and cold water immersion with lower body neoprene will be completed seated with water to shoulder level. Your heart rate will be taken throughout the recovery period. During immersion, your temperature will be taken at six and 12 minutes. At the end of the 12-minute recovery, you will have another five-min period where a third blood sample will be obtained, you will rate your perceived recovery, your temperature will be taken, and you will change back into your biking attire if needed. Afterwards, you will complete a fourth Wingate and a cool down. One week later you will return and repeat the same exact testing procedures as before except with the other recovery modality. In all, total sprint time will take two minutes over two different testing days. Your total time for testing day one and two is

Initial______

APPENDIX C (continued)

approximately 50 minutes each or 100 minutes total. Total participation time for this project is approximately 120 minutes or two hours.

4. Risks of Participation

The risks involved in this project are no greater than the risks you freely assume when you exercise. Moreover, sprints are variations of exercises you may do while working out. Hence, the risks are small; they include skeletal muscle injury and possibly a cardiac event, which could be fatal. The chances of a cardiac event are low in your age group. You may also have sore muscles 24 to 48 hours after the tests; the fingertip that is lanced may also be tender for a few days. Additionally, cold water immersion can be

uncomfortable and if at any point in time you feel discomfort you can withdraw from the study. To minimize risks, you will warm-up and cool-down before and after each test and training session. If you feel poorly during the test, you may terminate it at any time. At every testing sessions, there will be research technicians that are either CPR or First Aid certified. Some hold both certifications. These technicians will promptly provide standard first aid procedures in the event you are injured. If warranted, the research technician present during the test, will provide immediate care and will call 911 to seek additional assistance. There is also a risk of loss of time to you that could be spent studying, training or doing other leisure activities.

5. Compensation for Injury

Only students can go to the health center if they have an injury. If you suffer an injury that requires any treatment or hospitalization as a direct result of this study, the cost for such care will be charged to you. If you have insurance, you may bill your insurance company. You will be responsible to pay all costs not covered by your insurance. Ithaca College will not pay for any care, lost wages, or provide other financial compensation.

6. If You Would Like More Information about the Study

You can contact Edward Mussi at emussi@ithaca.edu, 734-255-5233 or Tom Swensen at tswensen@ithaca.edu

7. Withdraw from the Study

Participation is voluntary and you are free to withdraw from the study at any time before all stages of the testing have been completed.

Initial______

APPENDIX C (continued)

8. How the Data will be Maintained in Confidence

Ithaca College will protect information about you and your participation in this study. Subject information is confidential will be kept on a password protected computer. Hard copies of subject data will be kept in a locked file cabinet. All data will be kept for at least three years.

I have read the above and I understand its contents. I agree to participate in the study. I acknowledge that I am 18 years of age or older.

____

Print or Type Name

____________________________________ __________________

Signature **Date**

APPENDIX D

Health History Questionnaire

ID:____

Age:__________

Weight:_______

Sex:___________

1. Medical/Health History: Check if you ever had?

Heart disease/ Stroke	
Heart Murmur	
Skipped, rapid beats, or irregular heart rhythms	
High blood Pressure	
Lung Disease	
Diabetes	
Epilepsy	
Injuries to back, hips, knees, ankles, or feet	

Other conditions/comments:

Present Symptoms: Check within the box if you have you had these symptoms within the last 6 months?

Chest Pain	
Shortness of Breath	
Lightheadedness	
Heart Palpitations	
Loss of Consciousness	
Illness, surgery, or hospitalization	
Ankle/Leg swelling	
Joint/muscle injury requiring medical treatment	
Allergies (i.e. neoprene)	

Other conditions/comments:

APPENDIX D (continued)

List all medications presently taking:

2. **Exercise habits:**

Do you presently engage in physical activity? (circle one)

Yes **No**

How many times per week do you currently exercise?

How hard do you exercise? (circle one)

Easy Moderate (can carry on a conversation) Hard (can't carry on a conversation)

APPENDIX E

24-Hour Health Recall

ID Number: ______________________ Date: ______________

Diet

Has your diet changed drastically since the last exercise test?

[ ] Yes [ ] No

If so, please describe:

Have you consumed alcohol in the last 24 hours? (circle one)

Yes No

Have you used caffeine (e.g., coffee) or nicotine (e.g., cigarettes) in the last 3 hours? (circle one)

Yes No

Did you eat any food in the last three hours?

If so, please describe:

Injury

Have you experienced any sort of physical pain in the last 24 hours?

[ ] Yes [ ] No

If so, please explain:

Is there any possible physical injury we should know about before performing the test?

[ ] Yes [ ] No

If so, please explain:

Has there been any changes since the last exercise test that you feel could compromise your performance on today's exercise test?

[ ] Yes [ ] No

If so, explain:

Other questions/comments/concerns please state below.

APPENDIX F

Wingate Protocol

The subject will perform a Wingate bicycle test. The subject will cycle at a self-selected pace for 5 min for a warm up. The subject then will began cycling at 60rpm for approximately ten seconds with no weight (resistance). The test administrator will verbally count three, two, one, go. On the word “go”, the administrator will lower the test weight (7.5% of the testers bodyweight) on the bike and the subject will begin to accelerate maximally and try to maintain maximal speed throughout the entire 30-second test. The test administrator will count down the final three seconds of the test to a verbal “stop” signal. This test was utilized to calculate power and create fatigue.

APPENDIX G

Blood Lactate Guidelines & Blood-Borne Pathogen Safety Procedures

Blood-Borne Pathogen Safety Procedures

1. Wearing of rubber gloves
2. Using separate gloves for each subject
3. Wearing of safety glasses
4. Using appropriate biohazard bins
    a. Hard containers for sharps
    b. Larger containers with labeled bags for soiled, non-sharp objects
5. Using disposable surface covers for any surface that may come in contact with blood is possible
6. Using 10% bleach or other similar solutions to clean up contaminated areas

Blood Lactate Guidelines

Prior to testing check system calibration--- run both low and high solutions

1. Send subject to wash hands
2. Put on fresh pair of gloves
3. Put out three lactate strips on cart
4. Wipe subject's finger with alcohol prep pad
5. Dry area with Kimwipe
6. Lance the subject's fingertip
7. Squeeze out first drop of blood
8. Wipe this drop away with a Kimwipe
9. Squeeze out a fresh drop
10. Put lactate strip into analyzer; if test mode doesn't activate, hit the large triangular button on bottom of the analyzer
11. Place lactate strip into side of blood droplet and place analyzer on the cart
12. Wipe away blood drop with Kimwipe and hold down on the finger
13. Record lactate level
14. Collect two more samples following aforementioned procedures
15. Apply bandaid to subject's finger

APPENDIX H

Rating of Perceptual Recovery Scale

Rating	Definition
0	Nothing at all
0.5	Very, very little recovery
1	Very little recovery
2	A little recovery
3	Somewhat recovered
4	
5	Moderately recovered
6	
7	A lot of recovery
8	
9	Mostly recovered
10	Complete recovery