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The Effectiveness of Whole Body Cryotherapy Compared to Cold Water Immersion:
Implications for Sport and Exercise Recovery

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Abstract

Background: Cryotherapy is the process of cooling the body, is typically used therapeutically, and is often used as a method of recovery relative to sport and exercise performance. The purpose of this review is to compare the current literature on WBC to that of CWI and determine whether WBC provides any additional enhancements for sport and exercise recovery. These include tissue temperature reduction, markers of muscle damage, markers of inflammation, and parasympathetic reactivation. **Method:** Common methods of cryotherapy include cold water immersion (CWI), ice packs, ice massages, and gel or cooling creams. CWI is the most common method among athletes; however, a new form of cryotherapy, known as whole-body cryotherapy (WBC), has recently emerged. Since its introduction, WBC has grown in popularity among practitioners and athletes. WBC involves short exposures (generally between 2-4 minutes) to very cold air (-100o C to -140o C) in a controlled room and setting. Furthermore, many of the studies on WBC were observational and did not contain a control group. **Conclusion:** Despite its growing popularity, the alleged benefits of WBC are largely based on anecdotal evidence as randomized, clinically-controlled studies regarding its efficacy are limited.

Keywords: cryotherapy, cold water immersion, exercise, recovery, muscle damage, inflammation

1. Introduction

Cryotherapy is the process of cooling the body for therapeutic use and is typically used as a method of recovery from sport and exercise. Common methods of cryotherapy include cold water immersion (CWI), ice packs, ice massages, and gel or cooling creams. CWI is the most common method among athletes and most reviewed in literature (Bleakely et al., 2012). However, a new form of cryotherapy has recently emerged. Although first used in Japan in the late 1970s, whole-body cryotherapy (WBC) was not introduced to Europe until 1982 and America in the last 15 years (Costello et al., 2012). Since its introduction, WBC has grown in popularity among athletes and is becoming more accessible (Bleakley et al., 2014; Banfi et al., 2010). WBC involves short exposures (generally between 2-4 minutes) to very cold air (-100^{o} C to -140^{o} C) in a controlled room and setting. Individuals wear minimal clothing during treatment to protect sensitive areas from cold-related injuries.

Despite its growing popularity, support for WBC is largely based on anecdotal evidence as randomized, controlled studies regarding its efficacy are limited (Banfi et al. 2010). Many of the studies on WBC were observational and did not involve a control group. A recent review (Banfi et al., 2010) attempted to synthesize the current data on WBC, but must be viewed with caution as the findings are preliminary and based on relatively few initial studies. More advanced controlled randomized studies concerning WBC have recently begun to appear in the literature, thus allowing for more insight into its efficacy. The reported effects of WBC are similar to those of CWI including tissue temperature reduction and reduction in markers for muscle damage and inflammation. Bleakley et al. (2014) recently reviewed the efficacy and effectiveness of these claims using 10 relevant controlled studies and found most of the claims appear to have some merit. However, comparisons were not made to data regarding CWI as being the current standard in cryotherapy. No study or review has determined whether WBC provides any additional benefits to the athletes beyond CWI, despite being significantly more expensive.

The purpose of this review is to compare the current literature on WBC to that of CWI and determine whether WBC provides any additional enhancements for sport and exercise recovery. To do so, several markers of physiological changes associated with common theories of sport recovery were chosen for comparison (White & Wells, 2013). These include tissue temperature reduction, markers of muscle damage, markers of inflammation, and parasympathetic reactivation. This review will strictly compare the data on WBC to CWI and is not intended to cover the safety of either method, as to the authors' best knowledge all current literature shows both to be safe for healthy participants (Bleakley et al., 2012; Bleakley et al., 2014; Banfi et al., 2010).

2. Whole Body Cryotherapy Compared to Cold Water Immersion

2.1 Skin and Tissue Temperature

Exercise is known to cause an increase in skin temperature (Fröhlich et al., 2015; Fröhlich et al., 2014). However, the reduction of tissue temperature is a key component during recovery as it is a limiting factor for many pathways causing secondary damage (White & Wells, 2013; Bleakley & Davison, 2010). The decreased tissue temperature causes a lower nerve conduction velocity, limiting spasms and pain sensations, and vasoconstriction leading to decreased swelling and inflammatory signaling (White & Wells, 2013). Body cooling for recovery occurs at three levels: superficial, deep muscular, and core. Studies measuring the change in temperature for muscle and core from WBC are extremely limited. To date, only one study (Costello et al., 2012) has measured the intramuscular tissue temperature before and after WBC. Using data from Bleakley et al. (2014), Table 1 was constructed to show the magnitude of temperature reduction recorded from multiple studies for WBC and CWI. From this data, it appears that WBC could potentially be more effective at cooling superficial tissue when compared to CWI. The reductions in superficial tissue temperature are likely greater from WBC due to the larger difference in the temperature between WBC and the individual compared to CWI (~150º C versus ~20º C). However, one study directly compared temperature reduction between both modalities and found that, while skin temperature was significantly lower immediately following WBC compared to CWI, by 20 minutes post-treatment CWI actually resulted in significantly lower skin temperatures which lasted through 60 minutes (Costello et al., 2012). Other studies did not continue to record skin temperature past initial post-treatment measurements. This draws into question if the lower initial skin temperature from WBC can actually result in any extra benefits due to the short amount of time it appears to provide a significantly lower skin temperature than CWI.

Table 1. Skin, muscle, and core temperature reductions for WBC and CWI

	WBC (2-4 minutes, -110º C to -120º C)	CWI (5-10 minutes, 8º C to 14º C)
Skin Temperature	10.3 (Costello et al., 2013)	6.2 (Gregson et al., 2011)
	12.1 (Costello et al., 2012)	8.4 (Costello et al., 2012)
	13.7 (Hausswirth et al., 2013)	9 (Costello et al., 2013)
	16.9 (Zalewski et al., 2013)	16 (Gregson et al., 2011)
	19.4 (Westerlund et al., 2003)	
Muscle Temperature	1.2 (Costello et al., 2012)	1.67 (Gregson et al., 2011)
		1.7 (Costello et al., 2012)
Core Temperature	0 (Westerlund et al., 2003)	0.2 (Gregson et al., 2011)
	0.3 (Costello et al., 2012)	0.2 (Bailey et al., 2007)
		0.4 (Costello et al., 2012)
		0.4 (Peiffer et al., 2010)

The difference in temperature reduction between the two modalities is relatively small considering the large temperature difference. A possible explanation for this involves the thermal conductivity of the medium used in each method, air and water. At -110° C, the thermal conductivity of air is only 0.0151 W/mK (found using linear interpolation from known air conductivities at -100°C and -150°C) while water at 10° C has a thermal conductivity of 0.5846 W/mK. Heat transfer occurs from high to low temperatures, meaning that water (CWI) is much more efficient at extracting heat than air (WBC). This allows CWI to make up much of the difference in temperature to WBC through greater thermal conductivity.

The tissue temperature difference between the modalities no longer exists at deeper tissue levels. Muscle and core temperature both have minimal temperature decreases regardless of the method used. Neither WBC nor CWI are effective at lowering intramuscular or core temperature despite the comparatively large decrease in superficial tissue temperature. This is because superficial tissue cools in a linear pattern faster than deeper tissue (Yanagisawa et al., 2007). The thermal gradient between the medium and muscle also affects the magnitude of temperature change in the muscle (Yanagisawa et al., 2007). Deeper tissue is insulated by subcutaneous adipose tissue under the skin that has a low thermal conductivity (0.23 W/mK) (El-Brawany et al., 2009). This prevents much of the heat transfer from occurring within deeper tissue.

Another comparable aspect regarding tissue temperature is not the amount each method can lower skin temperature, but rather the minimal skin temperature each can cause. Knight (1976) found that to lower metabolic enzyme activity by approximately 50% a skin temperature around 11° C is required and to reduce nerve conduction velocity by 10% a skin temperature of 12.5° C is needed. Also, localized analgesia requires a skin temperature below 13.6° C (Westerlund et al., 2003). The lowest skin temperature recorded in any of the CWI studies did not reach 13.6° C (Costello et al., 2012;

Costello et al., 2013; Gregson et al., 2011), meaning that CWI appears limited in its effectiveness to cause these desired effects. WBC has demonstrated moderately more success with one study (Zalewski et al., 2013) having 2 of 8 measured body parts with temperatures low enough to achieve all three effects and another study (Westerlund et al., 2003) recording 4 of 9 body parts with temperatures low enough for all three effects. However, several other WBC studies showed minimum temperatures not dropping to the highest 13.6° C mark, much like CWI (Costello et al., 2012; Costello et al, 2013; Hausswirth et al., 2013). Taking these numbers into account, neither method is consistently effective at lowering skin temperature enough to maximize these desired benefits, but both have merit in achieving these goals on a limited basis. Nevertheless, WBC does not appear to provide any additional benefit in reducing tissue temperature over CWI.

2.2 Muscle Damage

As can be seen in Table 2, several markers of muscle damage are commonly used throughout the literature. These methods include biochemical markers, force production capability, and subjective means such as rating perceived muscle soreness. As reviewed by Warren et al. (1999), each method has its benefits and pitfalls. In order to provide the most comprehensive view on the effect of WBC and CWI on muscle damage, this section will focus on three measures: maximum voluntary contraction (MVC), blood levels of creatine kinase (CK), and perception of delayed onset muscle soreness (DOMS). These measures were chosen to provide a comprehensive view on the effects of WBC and CWI from immediately post-treatment to several days later through objective and subjective means. A loss in MVC is the first effect of exercise induced muscle damage (EIMD), occurring nearly immediately (Warren et al., 1999). This allows insight into whether WBC or CWI has an immediate impact on muscle damage. Elevated levels of CK in the blood do not appear until at least 24 hours following EIMD, allowing analysis of WBC and CWI abilities to alleviate later signs of EIMD (Warren et al., 1999). Subjective ratings of DOMS can provide perspective into the perceived effectiveness of each cryotherapy method from the standpoint of the participants (Warren et al., 1999). While hard to quantify through objective scientific means, DOMS remains important as the perception of recovery can influence the mental well-being of those recovering from sport and exercise.

Table 2. Overview of studies showing improvements vs. no effect for WBC and CWI during recovery from EIMD based on selected measurements. * indicates information taken from review or meta-analysis involving many individual studies + study involved untrained and trained subjects who demonstrated different responses to WBC.

	MVC	MVC	CK	CK	DOMS	DOMS
	Significant Effect	Insignificant Effect	Significant Effect	Insignificant Effect	Significant Effect	Insignificant Effect
WBC	Hausswirth et al., 2011; Fonda et el., 2013	Costello et al., 2012	+Wozniak et al., 2007; Banfi et al., 2009	Hausswirth et al., 2011; +Wozniak et al., 2007; Fonda et al., 2013; Ziemann et al. 2012	Hausswirth et al., 2011; Fonda et el., 2013	Costello et al., 2012
CWI	Bailey et al., 2007; *Leeder et al., 2012; Pournot et al., 2011	Glasgow et al., 2008; Goodall & Howatson, 2008	*Leeder et al., 2012*; Pournot et al., 2011	Bailey et al., 2007; Glasgow et al., 2008; Goodall & Howatson, 2008	Bleakley et al., 2012; Bailey et al., 2007; *Leeder et al., 2012; Machado et al., 2016	White et al., 2014; Glasgow et al., 2008; Goodall & Howatson, 2008; Pournot et al., 2011

Neither WBC nor CWI are able to prevent the immediate loss in MVC after EIMD. All studies showed insignificant differences between control and treatment groups when measurements were taken directly post- recovery intervention (Bailey et al., 2007; Hausswirth et al., 2011; Costello et al., 2012; Fonda & Sarabon, 2013; Leeder et al., 2012; Glasgow et al., 2014; Goodall & Howatson, 2008; Pournot et al., 2011). This suggests that WBC and CWI are both ineffective means to prevent the initial loss in MVC. Although, after one hour several have shown statistically significant improvements in MVC for groups who underwent either WBC or CWI (Bailey et al., 2007; Hausswirth et al., 2011; Fonda & Sarabon, 2013; Leeder et al., 2012; Pournot et al., 2011). While statistically significant, neither WBC nor CWI demonstrated large improvements in these studies and several studies continued to show no improvement from control for either method (Costello et al., 2012; Glasgow et al., 2014; Goodall & Howatson, 2008). It is difficult to say whether the improvements would translate into functionally significant changes in a clinical setting. The differences seen in the literature could be a result of inconsistent protocols for inducing EIMD. All the reviewed studies used their own variations of exercises in an attempt to cause EIMD. Until an accepted standardized method for inducing EIMD is presented, it is likely that the literature will continue to show mixed results. Consistency was mostly shown for the measurement of MVC as all but one of the reviewed studies used the knee extensors for measurements (Bailey et al., 2007; Hausswirth et al., 2011; Costello et al., 2012; Fonda & Sarabon, 2013; Goodall & Howatson, 2008; Purnot et al., 2011). The other study used knee flexion to measure MVC (Glasgow et al., 2014). At this time, there is no discernable difference between the effects of WBC and CWI on MVC following EIMD, as neither shows a consistent ability to positively effect this marker of muscle damage.

The literature is compelling, however, when it comes to the insignificant effect of WBC and CWI on the levels of CK in the blood 24 and 48 hours post exercise. Almost all data currently available for WBC shows no effect at lowering CK levels post-exercise. The first two studies to measure CK after WBC show significant reductions which may have led to many of the initial claims that WBC is effective at limiting the appearance of CK (Wozniak et al., 2007; Banfi et al., 2009). The first study by Wozniak et al. (2007) was only able to show this reduction in 10 untrained men after one session of WBC who did not complete any activity beforehand. However, the levels of CK were not elevated prior to WBC as in all the more recent studies, and there was no control group for comparisons. The same study also involved 21 trained kayakers who completed multiple sessions of training and WBC over a 10-day training period (Wozniak et al., 2007). After the 10 days there was no significant reduction in CK levels in the kayakers, indicating WBC to have no positive effect on CK levels (it should be noted there was also no control group for the kayakers). The second study completed by Banfi et al. (2009) showed a reduction in CK levels after WBC, but was purely observational and also contained no control group; therefore, any conclusions drawn from this study should be done with caution. More recently, higher-quality, experimental studies (Hausswirth et al., 2011; Fonda & Sarabon, 2013; Ziemann et al., 2012) examining the effect of WBC on CK levels post-exercise clearly indicate that WBC is ineffective at limiting CK appearance.

Most of the same can be said when reviewing the effect of CWI on CK levels post exercise. Leeder et al. (2012) conducted a meta-analysis into the effects of CWI on recovery and found that CWI does have a significant effect in reducing the efflux of CK from skeletal muscle, but also stated that through additional testing the effect is very minimal. Combining this finding with the several studies (Bailey et al., 2007; Glasgow et al., 2014; Goodall & Howatson, 2008) showing no difference in CK levels following CWI compared to controls it is clear that CWI, like WBC, does not cause significant changes in CK levels. Based on the current literature, WBC and CWI appear to be ineffective at reducing the appearance of CK in the blood following EIMD. Therefore, based on this biochemical marker the data suggest that neither method appears to help reduce or alleviate muscle damage.

Based on objective measures, neither WBC nor CWI are effective at reducing muscle damage, but DOMS, a more subjective measure, shows there could be merit to using WBC or CWI as a sport and exercise recovery method. The data overwhelmingly shows a positive effect from CWI on reducing DOMS. This holds true 24, 48, and even 72 hours post-exercise across most of the literature (Bleakley et al., 2012; Leeder et al., 2012; Machado et al., 2016). Multiple reviews (Bleakley et al., 2012; Machado et al., 2016) and meta-analyses (Leeder et al., 2012; Machado et al., 2016) have drawn conclusions from dozens of studies that CWI is very effective and strongly reduces DOMS. The four individual CWI studies (White et al., 2014; Glasgow et al., 2014; Goodall & Howatson, 2008; Pournot et al., 2011) not showing improvements in DOMS compared to a control are because the results proved to be statistically insignificant. However, all four still showed lowered DOMS ratings for CWI compared to a passive control. The difference in these individual studies could be explained by the participants used in each study. The individual studies were limited by smaller sample sizes compared to the meta-analyses, which could explain the insignificant findings despite lower DOMS ratings. WBC also appears to have a positive effect at lowering DOMS (Hausswirth et al., 2011; Fonda & Sarabon, 2013), but one study by Costello et al. (2012) did not find any significant reduction in DOMS after WBC. In this study, muscle soreness was rated higher under the cold condition compared to control at 24, 48, and 72 hours post-exercise, which did not happen in any of the other studies reviewed in the literature on CWI. The results were insignificant, but are still enough to cast doubt on the effectiveness of WBC to reduce DOMS due to the limited amount of studies available. Currently, it is suggested that CWI is more effective at reducing DOMS 24, 48, and 72 hours post-exercise compared to WBC. It should be noted, though, that more research is needed on WBC to confirm this suggestion.

2.3 Inflammation

Much of the anti-inflammatory properties of WBC and CWI rely strongly on the ability of each method to cool tissue. The effectiveness of each method to achieve this goal has been previously discussed in the previous section entitled "Tissue Temperature." Cooling the tissue helps control the inflammation process caused by EIMD by limiting secondary damage through means such as lowering nerve conducting velocity to reduce pain and spasms. Another means of reducing inflammation through cryotherapy is vasoconstriction. Two reviews (Bleakley et al., 2012; Leeder et al, 2012) suggest that CWI is able to cause cold-induced vasoconstriction thus altering blood flow (Wilcock et al., 2006). This process is theorized to be able to reduce lymphatic and capillary cell permeability causing decreased fluid diffusion into the interstitial space and thus assisting in limiting inflammation due to exercise (Wilcock et al., 2006). Gregson et al. (2011) showed whole limb blood flow to be reduced by nearly 40% in the femoral artery after 10 minutes of CWI (8° C). Yanagisawa et al. (2007) showed that this reduction of blood flow has a continued effect into the post-cooling phase. To the authors' best knowledge there are no current studies examining the effect of WBC on blood flow reductions. As a result, it can only be theorized that WBC could cause the same cold-induced vasoconstriction based on similar tissue temperature readings. Further research is needed to identify whether WBC can result in blood flow reductions.

Current data supporting WBC's ability to limit inflammation focuses on measurements of inflammatory biomarkers before and after treatment. Initial studies have shown generally positive results with reductions in the pro-inflammatory cytokines, TNFα (Ziemann et al., 2012; Ziemann et al., 2013), IL-1β (Pournot et al., 2011), and C-reactive protein (Pournot et al., 2011) and increases in the anti-inflammatory IL-10 (Banfi et al., 2009; Ziemann et al., 2013; Lubkowska et al., 2011), and IL-ra (Pournot et al., 2011) cytokines. However, these studies should be interpreted with caution due to the fact that they were completed under various conditions, not strictly looking at post-exercise recovery. One study was testing WBC on inflammation in obese men (Ziemann et al, 2013), and three others were done over multiple session rather than one session (Ziemann et al., 2012; Ziemann et al., 2013; Pournot et al., 2011). Two studies have also noted no changes in TNFα, IL-10, IL-1β, and IL-6 after WBC compared to passive control groups (Pournot et al., 2011; Leppaluoto et al., 2008). Literature and knowledge on the effect of WBC on sport- and exercise-induced inflammation is very limited. Current research appears to show both WBC and CWI can reduce the inflammation process following sport and exercise, but the mechanisms and pathways for this phenomenon remain speculative.

2.4 Parasympathetic Reactivation

In the clinical setting, cardiac parasympathetic reactivation following sport and exercise is not usually discussed as an important means of recovery compared to reducing tissue temperature and muscle damage. Recovery, though, is the process of returning oneself to a former or better condition. The cardiovascular system is vital in this process as it facilitates many of the other physiological processes such as thermoregulation and delivery/removal of nutrients and waste products (Stanley et al., 2013). Elevated parasympathetic activity allows for rapid cardiodeceleration and faster recovery (Fourtney & Vroman, 1985; Stanley et al, 2012). It is thought that this is mainly caused by the baroreflex triggered by cold-induced vasoconstriction and subsequent elevations in central blood volume (Bleakley et al., 2014; Stanley et al., 2013). It is beyond the scope of this review to detail all the benefits of parasympathetic reactivation and mechanisms of cardiovascular control so our readers are directed to other reviews (Stanley et al., 2013; Coote & Bothams, 2001). A recent review (Stanley et al., 2013) found that complete cardiac autonomic recovery after a single aerobic-based training session can take up to 24 hours following low-intensity exercise, 24-48 hours following threshold-intensity exercise, and at least 48 hours following high-intensity exercise. This is due to increased sympathetic activity post-exercise and decreased parasympathetic tone (Stanley et al., 2013). The time it takes to return to full body homeostasis largely depends on the timing and magnitude of parasympathetic reactivation (Hausswirth et al., 2013; Stanley et al., 2013; Fourtney et al., 1985; Stanley et al., 2012; Stanley et al., 2013; Buchheit et al., 2009; Park et al., 1999; Westerlund et al, 2006; Schaal et al., 2013). A standard and accepted method of assessing cardiac parasympathetic activity is measuring heart rate variability (Task Force, 1996). Therefore, this review has used studies measuring heart rate variability indices such as the square root of the mean-squared differences of the R-R interval (RMSSD).

A phenomenon known as "cold shock" is well documented in the literature as the initial response upon immediate exposure to CWI (Bleakley & Davison, 2010). Cold shock leads to an increase in sympathetic activity (Bleakley et al., 2010) which would seem to be counter-intuitive to parasympathetic activation. Current literature also shows this phenomenon to be relatively short-lived and less prominent in athletes accustomed to CWI (Bleakley & Davison, 2010). Despite the initial cold shock and increase in sympathetic activity, CWI has proven to be very successful at significantly increasing parasympathetic reactivation post-exercise compared to passive recovery (Stanley et al, 2012; Stanley et al., 2013; Buchheit et al., 2009; Park et al., 1999; Parouty et al., 2010; Al Haddad et al., 2010). The increase in parasympathetic reactivation following CWI has been shown to hold true after supramaximal (Stanley et al., 2012; Stanley et al., 2013; Buchheit et al, 2009; Parouty et al., 2010) and submaximal (Al Haddad et al., 2010) exercise. It is clear in current literature that CWI has a profound ability to significantly increase parasympathetic reactivation post-exercise. However, it remains unclear how much of this effect is due to the hydrostatic pressure of water versus the temperature of water. Two studies also demonstrated a significant increase in parasympathetic reactivation from participants in thermo-neutral water compared to passive recovery (Park et al., 1999; Al Haddad et al., 2010). Another study (Stanley et al., 2012) also established a contrast water therapy protocol to have a significant effect. In all three studies, CWI showed a greater increase in parasympathetic reactivation compared to thermo-neutral or contrast immersion, but the differences were insignificant (Stanley et al., 2012; Park et al., 1999; Al Haddad et al., 2010). Further research needs to be done to differentiate the effects of hydrostatic pressure versus temperature during water immersion on parasympathetic reactivation.

Fewer studies have been completed regarding WBC and parasympathetic activation, but initial studies have shown positive results (Hausswirth et al., 2013; Westerlund et al., 2006; Schaal et al., 2013). WBC appears to produce the same "cold shock" as CWI resulting in an initial increase in sympathetic activity (Hausswirth et al., 2013). All three have shown significant and large [RMSSD +53% (Westerlund et al., 2006), +78% (Schaal et al., 2013), +85.2% (Hausswirth et al., 2013)] increases in parasympathetic activation. Only one of the studies, however, has examined the specific effects of reactivation following exercise (Schaal et al., 2013). The other two were completed on individuals at rest prior to completing WBC and were focusing on initial activation since sympathetic activity was not previously heightened (Hausswirth et al., 2013; Westerlund et al., 2006). Thus, while initial data is promising, there is currently not enough data to draw definitive conclusions on the effects of WBC on parasympathetic reactivation post-exercise. Until further research can be completed on WBC and parasympathetic reactivation following exercise, CWI is recommended for use to help improve recovery through greater parasympathetic activation.

3. Discussion

Future research should focus on the need for higher-quality experimental studies concerning WBC. Randomized and controlled studies are severely lacking on many aspects of WBC, as most of the present literature consists of preliminary studies with lower-quality experimental design. Higher-quality experimental studies will allow for more definitive insights and conclusions on the effects of WBC for sport and exercise recovery. There is also a need for more studies on both CWI and WBC involving females. Females are majorly underrepresented in the current literature regarding CWI and WBC. Many studies involved only a few women and did not differentiate results between the males and females, and several others included no females as participants.

Current research specifically designed to measure effects of WBC on recovery has a major gap in clinical and practical application. In all the current studies, WBC was completed in a series of three rooms with the final room being the main treatment at -110º C where each individual was completely exposed to the air. However, practically speaking, WBC is often completed by the athletic population in cryo-chambers where the individual's head is not exposed to the air. In the literature, this method is referred to as partial body cryotherapy (PBC) and involves colder air temperatures, approximately -160oC, produced from liquid nitrogen (Hausswrith et al., 2013). Few current studies have investigated this method (Hausswrith et al., 2013; Fonda & Sarabon, 2013), yet both methods are considered WBC in the clinical setting, but research is almost non-existent involving PBC. Thus, research is needed to investigate PBC as it is a commonly used method of WBC in the clinical environments. The difference in terminology between the literature and clinical application should be addressed as it could contribute to the apparent lack of research on PBC, but it is beyond the scope of this review. WBC does not provide an advantage over CWI at reducing tissue temperature. While WBC may provide a larger initial decrease in skin temperature, any advantage is likely limited or lost as the skin warms faster compared to CW (Costello et al., 2012). There is no difference between WBC and CWI at reducing muscle and core temperature as neither is proven to be effective. Current literature does not support claims that CWI or WBC can lower muscle or core temperature because neither is effective at lowering tissue temperature beyond the skin.

Various modalities that had been alleged to reduce muscle damage have been shown to be ineffective at doing so (Dabbs et al., 2014). Muscle damage can be measured by several markers and can be hard to quantify on a consistent basis across studies. The literature is inconclusive on the ability of CWI or WBC to improve MVC. Neither method is able to significantly improve MVC immediately post-exercise. However, research shows that at one hour post-recovery both CWI and WBC begin to demonstrate small, but significant increases in MVC compared to passive recovery. It has yet to be determined if this translates to functional or performance increases though. Neither CWI nor WBC affect CK levels in the blood post exercise. The only compelling and consistent support for CWI and WBC in alleviating muscle damage is a reduction in DOMS. This is a subjective measure based on the individual's perception of pain, but the literature suggests that CWI has a large positive effect on reducing DOMS, and it appears WBC does as well. However, based on biochemical measures, neither WBC nor CWI demonstrate an ability to reduce muscle damage. Both methods seem to reduce inflammation, but the pathways and mechanisms involved remain unclear. Differentiating between the ability of CWI and WBC to reduce inflammation is difficult as research regarding the two is largely incomparable. Based on individual evidence for each, however, there is potential for each in their ability to reduce inflammation. More focused research is needed on the mechanisms CWI and WBC use to reduce inflammation.

An often overlooked component of recovery, parasympathetic reactivation following exercise provides the most support for CWI and WBC as benefitting recovery. The ability of CWI to significantly increase parasympathetic reactivation post-exercise is one of the few scientific supports for CWI as a recovery method. CWI proved effective at creating large increases in parasympathetic activity following both supra- and sub-maximal exercise. Initial data supports WBC's ability to increase parasympathetic activity, but more data is needed to confirm its effect on reactivation following exercise. CWI is suggested as a better means of increasing parasympathetic reactivation post-exercise compared to WBC as there may also be a positive influence by hydrostatic pressure involved.

CWI is a more cost effective means of cryotherapy for individuals and teams than WBC while providing the same or greater benefits, and thus should be considered in comparison to WBC. Overall, the physiological effects of both are very comparable; however, a comprehensive review of the literature indicates no additional benefit of WBC over CWI. While the use of CWI as a method of sport recovery is slightly more supported in literature, it also remains controversial due to the lack of understanding of underlying mechanisms (Bleakley et al., 2012). Both methods should continue to be questioned and investigated for their ability to improve recovery from sport and exercise.

References

Al Haddad, H., Laursen, P., Chollet, D., et al. (2010). Effect of cold or thermoneutral water immersion on post-exercise heart rate recovery and heart rate variability indices. Autonomic Neuroscience, 156(1-2), 111-116.

Bailey, D.M., Erith, S.J., Griffin, P.J., et al. (2007). Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. *Journal of Sports Science*, 25(11), 1163-1170.

Banfi, G., Lombardi, G., Colombini, A., et al. (2010). Whole-body cryotherapy in athletes. *Sports Medicine*, 6, 509-517.

Banfi, G., Melegati, G., Barassi, A., et al. (2009). Effects of whole-body cryotherapy on serum mediators of inflammation and serum muscle enzymes in athletes. *Journal of Thermal Biology*, 34, 55-59.

Bleakley, C.M., Bieuzen, F., Davison, G.W., Costello, J.T. (2014). Whole-body cryotherapy: empirical evidence and theoretical perspectives. *Journal of Sports Medicine*, 5, 25-36.

Bleakley, C.M., Davison, G.W. (2010). What is the biochemical and physiological rationale for using cold-water immersion in sports recovery? A systematic review. *British Journal of Sports Medicine*, 44, 179-187.

Bleakley, C., McDonough, S., Gardner, E., et al. (2012). Cold-water immersion (cryotherapy) for preventing andtreating muscle soreness after exercise. *Cochrane Database Systemic Reviews*, 2, 1-136.

Buchheit, M., Peiffer, J.J., Abbiss, C.R., et al. Effect of cold water immersion on post-exercise parasympathetic reactivation. *American Journal of Heart and Circulation Physiology*, 296, H421-H427

Coote, J., Bothams, V. (2001). Cardiac vagal control before, during, and after exercise. *Experimental Physiology*, 86(6), 811-815.

Costello, J.T., Algar, L.A., Donnelly, A.E. Effects of whole-body cryotherapy (-110°C) on proprioception and indices of muscle damage. *Scandinavian Journal of Medicine and Science in Sports*, 22, 190-198.

Costello, JT., Culligan, K., Selfe, J., et al. (2012). Muscle, skin and core temperature after -110ºC cold air and 8ºC water treatment. *PlosOne*, 7(11), e48190.

Costello, J.T., Donnelly, A.E., Karki, A., et al. (2013). Effects of whole body cryotherapy and cold water immersion on knee and skin temperature. *International Journal of Sports Medicine*, 35(1), 35-40.

Dabbs, N., Brown, L., Garner, J. (2014). Effects of whole body vibration on vertical jump performance following exercise induced muscle damage. *International Journal of Kinesiology and Sport Science*, 2(1), 1-8.

El-Brawany, M.A., Nassiri, D.K., Terhaar, G., et al. (2009). Measurement of thermal and ultrasonic properties of some biological tissues. *Journal of Medical Engineering and Technology*, 33(3), 249-256.

Fonda, B., Sarabon, N. Effects of whole-body cryotherapy on recovery after hamstring damaging exercise: A crossover study. *Scandinavian Journal of Medicine and Science in Sports*, 23, 270-278.

Fourtney, S.M., Vroman, N.B. (1985). Exercise, performance and temperature control-temperature regulation during exercise and implications for sports performance and training. *Sports Medicine*, 2(1), 8-20.

Fröhlich, M., Ludwig, O., Zeller, P., Felder, H. (2015). Changes in skin surface temperature after a 10-minute warm-up on a bike ergometer. *International Journal of Kinesiology and Sport Science*, 3(3), 1-5,

Fröhlich, M., Ludwig, O., Kraus, S., Felder, H. (2014). Changes in skin surface temperature during muscular endurance indicated strain – an explorative study. *International Journal of Kinesiology and Sport Science*, 2(3), 1-5.

Glasgow, P.D., Ferris, R., Bleakley, C.M. (2014). Cold water immersion in the management of delayed-onset muscle soreness: Is foes important? A randomized controlled trial. *Physical Therapy in Sport*, 15, 228-233.

Goodall, S., Howatson, G. (2008). The effects of multiple cold water immersions on indices of muscle damage. *Journal of Sport Science and Medicine*, 7, 235-241.

Gregson, W., Black, M.A., Jones, H., et al. (2011). Influence of cold water immersion on limb and cutaneous blood flow at rest. *American Journal of Sports Medicine*, 39(6), 1316-1323.

Hausswirth, C., Louis, J., Bieuzen, F., et al. (2011). Effects of whole-body cryotherapy vs. far-infrared vs. passive modalities on the recovery from exercise-induced muscle damage in highly-trained runners. *PlosOne*, 6(12), e27749.

Hausswirth, C., Schaal, K., Meur, Y.L, et al. (2013). Parasympathetic activity and blood catecholamine repsonses following a single partial-body cryostimulation and a whole-body cryostimulation. *PlosOne*, 8(8), e72658.

Knight, K.L. (1976). Effects of hypothermia on inflammation and swelling. *Journal of Athletic Training*, 11, 7-10.

Leeder, J., Gissane, C., Someren, K.V., et al. (2012). Cold water immersion and recovery from strenuous exercise: a meta-analysis. *British Journal of Sports Medicine*, 46, 233-240.

Leppaluoto, J., Westerlund, T., Huttunen, P., et al. (2008). Effects of long-term whole-body cold exposures on plasma concentration of ACTH, beta-endorphin, cortisol, catecholamines and cytokines in healthy females. *Scandinavian Journal of Clinical and Laboratory Investigation*, 68(2), 145-153.

Lubkowska, A., Szygula, Z., Chlubek, D., et al. (2011). The effect of prolonged whole-body cryostimulation treatment with different amounts of sessions on chosen pro- and anti-inflammatory cytokine levels in healthy men. *Scandinavian Journal of Clinical and Laboratory Investigation*, 71, 419-425.

Machado, A.F., Ferreira, P.H., Micheletti, J.K., et al. (2016). Can water temperature and immersion time influence the effect of cold water immersion on muscle soreness? A systematic review and meta-analysis. *Sports Medicine*, 46, 503-514.

Parouty, J., Al Haddad, H., Quod, M., et al. (2010). Effect of cold water immersion on 100-m sprint performance in well-trained swimmers. *European Journal of Applied Physiology*, 109, 483-490.

Peiffer, J.J., Abbiss, C.R., Watson, G., et al. Effect of cold water immersion on repeated 1-km cycling performance in the heat. *Journal of Science and Medicine in Sport*, 13(1), 112-116.

Pournot, H., Bieuzen, F., Duffield, R., et al. (2011). Short term effects of various water immersions on recovery from exhaustive intermittent exercise. European Journal of Applied Physiology, 111, 1287-1295.

Pournot, H., Bieuzen, F., Louis, J., et al. (2011). Time-course of changes in inflammatory response after whole-body cryotherapy multi exposures following severe exercise. *PlosOne*, 6(7), e22748.

Park, K.S., Choi, J.K., Park, Y.S. (1999). Cardiovascular regulation during water immersion. *Applied Human Science*, 18, 233-241.

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.

Stanley, J., Peake, J.M., Buchheit, M. (2013). Cardiac parasympathetic reactivation following exercise: Implications for training prescription. *Sports Medicine*, 43, 1259-1277.

Stanley, J., Peake, J.M., 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.

Schaal, K., Le Meur, Y., Bieuzen, F., et al. (2013). Effect of recovery mode on post-exercise parasympathetic reactivation in elite synchronized swimmers. *Applied Physiology Nutrition and Metabolism*, 38, 126-133.

Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. (1996). Heart rate variability: standards of measurement, physiological interpretation, and clinical use. *Circulation*, 93(5), 1043-1065

Warren, G.L., Lowe, D.A., Armstrong, R.B. (1999). Measurements tools used in the study of eccentric contraction-induced injury. *Sports Medicine*, 27(1), 43-59.

Westerlund, T., Oksa, J., Smolander, J., et al. (2003). Thermal responses during and after whole-body cryotherapy (-110°C). *Journal of Thermal Biology*, 28, 601-608.

Westerlund, T., Uusitalo, A., Smolander, J., et al. (2006). Heart rate variability in women exposed to very cold air (-110°C) during whole-body cryotherapy. *Journal of Thermal Biology*, 31, 342-346.

White, G.E., Rhind, S.G., Wells, G.D. (2014). The effect of various cold-water immersion protocols on the exercise-induced inflammatory response and functional recovery from high-intensity sprint exercise. *European Journal of Applied Physiology*, 114, 2353-2367.

White, G.E., Wells, G.D. (2013). Cold-water immersion and other forms of cryotherapy: physiological changes potentially affecting recovery from high-intensity exercise. *Extreme Physiology and Medicine*, 2(1), 26.

Wilcock, I.M., Cronin, J.B., Hing, W.A. (2006). Physiological response to water immersion: a method for sport recovery. *Sports Medicine*, 36(9), 1-18

Wozniak, A., Wozniak, B., Drewa, G., et al. (2007). The effect of whole-body cryostimulation on lysosomal enzyme activity in kayakers during training. *European Journal of Applied Physiology*, 100, 137-142.

Yanagisawa, O., Homma, T., Okuwaki, T., et al. (2007). Effects of cooling on human skin and skeletal muscle. *European Journal of Applied Physiology*, 100, 737-745.

Zalewski, P., Klawe, J.J., Pawlak, J., et al. (2013). Thermal and hemodynamic response to whole-body cryostimulation in healthy subjects. *Cryobiology*, 66, 295-302.

Ziemann, E., Olek, R.A., Grzywacz, T., et al. (2013). Whole-body cryostimulation as an effective method of reducing low-grade inflammation in obese men. *Journal of Physical Science*, 63, 333-343.

Ziemann, E., Olek, R.A., Kujach, S., et al. (2012). Five-day whole-body cryostimualtion, blood inflammatory markers and performance in high ranking profession tennis players. *Journal of Athletic Training*, 47(6), 664-672