

EFFECT OF INTERMITTENT COOLING ON BASEBALL PITCHING AND CATCHING

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## ABSTRACT

Cryotherapy has been shown to be an effective method for reducing edema and inflammation, decreasing pain in acute injury, and is being studied as an aid in recovery. The traditional recovery treatment between innings for pitchers and catchers is to rest in the dugout. In this study, pitchers ( $n = 8$ ) threw two simulated games separated by 5-7 days for recovery. Participants were given 4 min of intermittent arm and shoulder cooling treatment (AC) or no cooling (NC) in between each of 5-simulated innings. Pitchers that received NC had a significant decrease in velocity over the 5 innings (4%); by contrast, pitchers that received AC maintained pitching velocity ( $p = 0.04$ ) (all-innings mean velocity  $31.2 \pm 2.1 \text{ m}\cdot\text{s}^{-1}$  versus  $30.6 \pm 2.2 \text{ m}\cdot\text{s}^{-1}$ ). Average pitch speed in the 4<sup>th</sup> inning and 5<sup>th</sup> inning was significantly faster for AC ( $31.3 \pm 2 \text{ m}\cdot\text{s}^{-1}$  and  $31.3 \pm 2 \text{ m}\cdot\text{s}^{-1}$ ) compared to NC ( $30 \pm 2 \text{ m}\cdot\text{s}^{-1}$  and  $30.4 \pm 2 \text{ m}\cdot\text{s}^{-1}$ ,  $p = 0.04$ ), respectively. Additionally, AC resulted in significantly lower perceived exertion (RPE) ( $p \leq 0.01$ ) and improved perceived recovery (PRS) ( $p \leq 0.01$ ) compared to NC in a temperate environment. In catchers ( $n = 6$ ), torso cooling (TC) resulted in a significantly lower RPE ( $p \leq 0.01$ ) and improved PRS ( $p \leq 0.01$ ) compared to NC. Significantly lower mean recovery HR was seen during the TC treatment compared to NC in the 5<sup>th</sup> ( $84 \pm 8$  vs.  $90 \pm 9$  bpm,  $p = 0.04$ ), 7<sup>th</sup> ( $84 \pm 3$  vs.  $92 \pm 7$  bpm,  $p = 0.02$ ), and 9<sup>th</sup> ( $85 \pm 7$  vs.  $93 \pm 5$  bpm,  $p = 0.01$ ) innings. Increase in rectal temperature was smaller in TC compared to NC ( $0.58 \pm 0.20$  °C vs.  $0.98 \pm 0.20$  °C,  $p = 0.01$ ). Working HR was significantly lower at the end of the TC when compared to NC ( $108 \pm 16$  vs.  $120 \pm 19$  bpm,  $p = 0.02$ ). Cryotherapy improved recovery during baseball pitching and catching, attenuated a decrease in pitching velocity as well as attenuated core temperature increases in catchers.

**Key Words:** cryotherapy, catching, pitching, thermoregulation, velocity, recovery

## LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	analysis of variance
cm	centimeter
kg	kilogram
C	Celsius
mph	miles per hour
<i>n</i>	sample size
<i>p</i>	probability associated with the occurrence under the null hypothesis of a value as extreme as or more extreme than the observed value
TC	torso cooling
AC	arm cooling/shoulder and forearm
NC	no cooling
HR	heart rate
DOMS	delayed-onset of muscle soreness
PAR-Q	Physical Activity Readiness Questionnaire
RPE	rating of perceived exertion
PRS	rating of perceived recovery scale
SD	standard deviation
SPSS	Statistical Package for the Social Sciences
=	equal to
<	less than
%	percent
NCAA	National Collegiate Athletic Association
s	Seconds

$\text{m}\cdot\text{s}^{-1}$       Meters per second

MLB      Major League Baseball

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## CHAPTER I

### INTRODUCTION

The throwing shoulder of a baseball pitcher is subjected to high stress as a result of the repetitive activity of pitching (Yanagisawa et al., 2003; Wight et al., 2004, Olsen et al., 2006). Baseball pitchers typically experience a loss of strength and increased soreness after pitching (Fleisig et al., 1995; Park et al., 2002; Yanagisawa et al., 2003). The negative effects of repetitive throwing may lead to decreases in performance as well as potential overuse injury. Olsen et al. (2006) reported a 4-fold increase in arm surgeries for collegiate pitchers and a 6-fold increase in arm surgeries for high school pitchers over the 5-year period 2000-2004.

Local tissue cooling, known as cryotherapy, is accepted as an effective method for reducing edema, inflammation, and promoting recovery (Bailey et al., 2007; Reilly and Ekblom, 2005). Cryotherapy has also been utilized as a means of decreasing pain and soreness in acute injury (Snyder et al., 2011; Cheung et al., 2003; Goodall et al., 2008; Howatson et al., 2008; Reilly et al., 2005; Marino 2002). Pitchers attempt to improve performance by effectively delaying the onset of fatigue, and local tissue cooling might help in this regard.

In addition to pitchers, cryotherapy may benefit baseball catchers as well. Catchers are involved in every pitch thrown during the game and must wear protective equipment which reduces heat loss. Catchers may catch up to 27 innings over the course of a 3-game series, with each regulation game lasting 9-innings. This scenario subjects catchers to a substantial heat load, particularly if the games are played in a hot environment, as is often the case since baseball is typically played in the spring and summer months.

Traditionally, the recovery treatment between innings for pitchers and catchers is to keep them in the dugout. However, cryotherapy may be an effective aid to baseball performance.

Few empirical studies have examined the effect of cryotherapy on baseball-specific recovery and activity (Verducci et al., 2001, Hannan et al., 1997, Yanagisawa et al., 2003), however.

Verducci (2000) investigated the effect of an intermittent cooling protocol on resistance training as well as baseball pitching (Verducci, 2001), noting that though the exact nature of muscle fatigue remains obscure, cryotherapy appeared to delay fatigue and increase throwing velocity without affecting accuracy. While the Verducci study (2001) provides insight into the potential effect of cryotherapy on baseball pitching, there are currently no empirical studies examining the effect of cryotherapy on core temperature during baseball catching.

The purpose of the study on pitchers was 3-fold: 1) to test the hypothesis that intermittent cooling of the shoulder and forearm would positively affect pitch velocity, 2) to determine if intermittent cooling affects subjective exertion for pitchers, and 3) to evaluate whether intermittent cooling is a viable method for perceived recovery following a long duration of pitching. The study on catchers tested the hypotheses that torso cooling (TC) would attenuate any increase in core body temperature, improve subjective recovery, and reduce perceived exertion in baseball catchers during a simulated game in a controlled, hot environment. The third study is a review of literature regarding to effects of cryotherapy on sport and exercise performance.

## STUDY I

### THE EFFECT OF INTERMITTENT ARM AND SHOULDER COOLING ON BASEBALL PITCHING VELOCITY

#### ABSTRACT

The throwing arm of a baseball pitcher is subjected to high stress as a result of the repetitive activity of pitching. Cryotherapy may facilitate recovery from this high stress, but this has not been tested. This study investigated the effects of cryotherapy on pitching velocity and subjective measures of recovery and exertion. Trained college-aged male baseball pitchers ( $n = 8$ ) threw 12 pitches (1 pitch every 20 s) per inning for five total innings of a simulated game. Between each inning, pitchers received shoulder and arm cooling (AC) or, on a separate occasion, no cooling (NC). All sessions took place in a temperate environment ( $18.3 \pm 2.8$  °C;  $49 \pm 4\%$  relative humidity). Pitch speeds were averaged for each participant each inning as well as overall for five innings. Perceived exertion (RPE) was recorded at the end of each simulated inning. Perceived recovery (PRS) was recorded after treatment between each inning. Mean pitching velocity for all-innings combined was higher ( $p = 0.04$ ) for shoulder and elbow cooling (AC) ( $31.2 \pm 2$  m·s<sup>-1</sup>) than for no cooling (NC) ( $30.6 \pm 2$  m·s<sup>-1</sup>). Average pitch speed in the 4<sup>th</sup> and 5<sup>th</sup> innings was significantly higher in AC ( $31.3 \pm 2$  m·s<sup>-1</sup> for both innings) compared to NC ( $30.0 \pm 2$  m·s<sup>-1</sup> and  $30.4 \pm 2$  m·s<sup>-1</sup>, for the 4<sup>th</sup> and 5<sup>th</sup> innings, respectively,  $p = 0.01$ ). AC resulted in a significantly lower RPE ( $p \leq 0.01$ ) and improved PRS ( $p = 0.01$ ) compared to NC. Intermittent cryotherapy attenuated velocity loss in baseball pitching, decreased RPE, and facilitated subjective recovery during a 5-inning simulated game.

**Key Words:** cryotherapy, exertion, throwing speed, recovery

## INTRODUCTION

The throwing elbow and shoulder of a baseball pitcher is subjected to high stress due to the repetitive nature and maximal force required for pitching (Matsuo et al., 2002; Yanagisawa et al., 2003; Wight et al., 2004, Olsen et al., 2006). Baseball pitchers typically experience soreness and a loss of strength after pitching (Fleisig et al., 1995; Park et al., 2002; Yanagisawa et al., 2003; Syzmanski, 2009). The negative effects of repetitive overhand throwing may lead to decreases in performance and lead to potential overuse injuries and surgery. Olsen et al. (2006) reported a 4-fold increase in arm surgeries for collegiate pitchers and a 6-fold increase in arm surgeries for high school pitchers over the 5-year period of 2000-2004. The increase in arm injuries could be the result of increases in games played per year as well as pitches thrown per year (Lyman et al., 2001). Regardless of the cause, the increase in arm injuries bring to light the importance of strategies to increase recovery and delay fatigue.

Traditionally, pitchers recover and minimize exertion between innings by resting in the dugout. Often, pitchers wear a jacket or place a towel on the throwing arm. The rationale for this practice is to keep the active muscles “loose” and warm. This recovery approach for pitchers contradicts current scientific evidence.

Effects of cryotherapy on the overuse symptoms of pain, swelling, and inflammation (Park et al., 2002; Bailey et al., 2007). Cold therapy on the shoulder and legs has been shown to increase muscle fiber activation (Piedrahita et al 2008; Pietrosimone et al., 2009), to help maintain repeated performance (Vaile et al., 2010), and to improve sprint performance (Castle et al., 2006). However, in a study by Hannan et al. (1997), neither pre-heating nor pre-cooling the arm for 20 min prior to pitching significantly.

Cryotherapy is also utilized to improve recovery (Bailey et al., 2007; Reilly and Ekblom, 2005; Yanagisawa et al., 2003). There are, however, conflicting results on the effect of local muscle cooling on delayed onset muscle soreness (DOMS) (Snyder et al., 2011; Cheung et al., 2003; Goodall et al., 2008; Howatson et al., 2008; Reilly and Ekblom, 2005; Marino, 2002). The equivocal findings among cryotherapy studies are likely due to diverse research methods and cryotherapy application times.

Only a few empirical studies have examined the effects of cryotherapy on baseball-specific activity (Verducci, 2001; Yanagisawa et al., 2003; Matsuo et al., 2002; Fleisig et al., 2009). Cold treatment has been shown to increase work (total repetitions) when applied intermittently (Verducci, 2000; 2001). In this study, Verducci (2001) performed intermittent cooling during baseball pitching and noted that although the exact nature of fatigue remains obscure, cryotherapy appeared to delay the onset of fatigue and increased throwing velocity of pitches without affecting accuracy. However, Verducci (2001) tested pitching performance on flat ground instead of a pitcher's mound and did not control for pitch count. Generally, baseball-pitching performance is limited to a predetermined number of pitches. Not using a pitcher's mound or controlling pitch count makes it difficult to evaluate pitching performance in an ecologically valid manner.

A more recent study by Yanagisawa et al. (2003) examined the effect of simulated-maximal pitching performance (98 pitches per trial) on recovery and shoulder strength using five different recovery methods. Yanagisawa and colleagues found that cryotherapy and cryotherapy combined with light shoulder exercise were the optimal methods for minimizing shoulder strength loss during shoulder abduction, internal/external rotation without shoulder abduction and maximizing 24-hour subjective recovery.

Given the lack of ecological validity in the aforementioned study (Verducci, 2001) and the fact that few empirical studies have been performed on baseball pitchers using intermittent cooling, the purpose of this study was to test the effect of a cryotherapy application on velocity, subjective exertion, and recovery time between innings during a simulated 5-inning game. The results and information derived from this study may be helpful for coaches, physical therapists, and athletic trainers with direct interaction with baseball players.

## **METHODS**

### *Participants*

Eight trained amateur male baseball pitchers with no previous history of elbow or shoulder injury were recruited and participated in this study ( $n = 8$ ,  $21 \pm 1$  yr;  $180 \pm 7$  cm). All participants were competitively trained players, throwing two or more times per week for  $> 20$  minutes for a minimum of 6-weeks prior to the beginning of the study. The local Institutional Review Board approved the study and participants completed an informed consent form prior to participating. All participants indicated they were free of any health, arm, or shoulder issues that could affect the results of their performance. Participants refrained from heavy exercise, ingestion of caffeine, and ingestion of alcohol during the 24 hours preceding a trial. Participants dressed in baseball attire: cap, baseball pants, socks, baseball shoes, practice jersey or comparable cotton shirt and belt provided by the respective baseball organization of each participant. Twenty-four hours after the familiarization session, participants performed the first of the two experimental trials.

### *Research design*

Trained collegiate pitchers were asked to throw fastballs at a target at the rate of one pitch every 20 seconds (Yanagisawa et al., 2003). An inning consisted of 12 pitches with each participant given six minutes of rest between innings to replicate the time for the opposing pitcher warming-up and completing an inning (Yanagisawa et al., 2003).

There were three sessions. All sessions took place outdoors at the same time of day on a baseball field. The first trial for each participant familiarized the participant with the protocol, followed by two simulated game trials. Ambient temperature and relative humidity (RH) were recorded (Figure 1). During the rest period, one of the two randomly selected treatments (counterbalanced overall among participants) was administered to assess any difference between intermittent ice bag cooling of the shoulder and forearm (AC) and no treatment (NC) on pitching performance.

Participants were allowed to warm-up prior to pitching each inning to insure they were “loose” and to minimize risk of injury. The warm-up consisted of participants throwing for duration of their choice. After the first inning, warm-ups before all subsequent innings were standardized for each participant between trials. Warm-up pitches were not counted toward the overall total. The pitching protocol included a maximum of 60 pitches thrown to simulate the first 5-innings of a baseball game. The 5-inning delineation is the minimum number of innings a pitcher must successfully complete to be granted a win in Major League Baseball (MLB).

There were two subjective scales used to determine perceived exertion and recovery. The Borg (1982) 6-20 rating of perceived exertion (RPE) scale and 10-0 rating of perceived recovery scale (PRS) were used to assess subjective sensations associated with recovery and exertion

during each trial. The Borg RPE scale is a subjective rating of effort being exerted during exercise (Borg, 1982). The Borg RPE scale is a 6-20 scalar representation of subjective intensity with 6 indicating no exertion and 20 indicating maximal exertion. The PRS is a subjective rating of recovery (Laurent et al, 2011) that was used at the beginning, between innings and end of each session. The PRS is a 0 -10 scalar representation of varying levels of an individual's perceived recovery status with 0 indicating no recovery and a 10 indicating full recovery. Each participant was familiarized with the RPE and PRS prior to testing. PRS recorded prior to the beginning of subsequent innings, with RPE was recorded at the end of each inning.

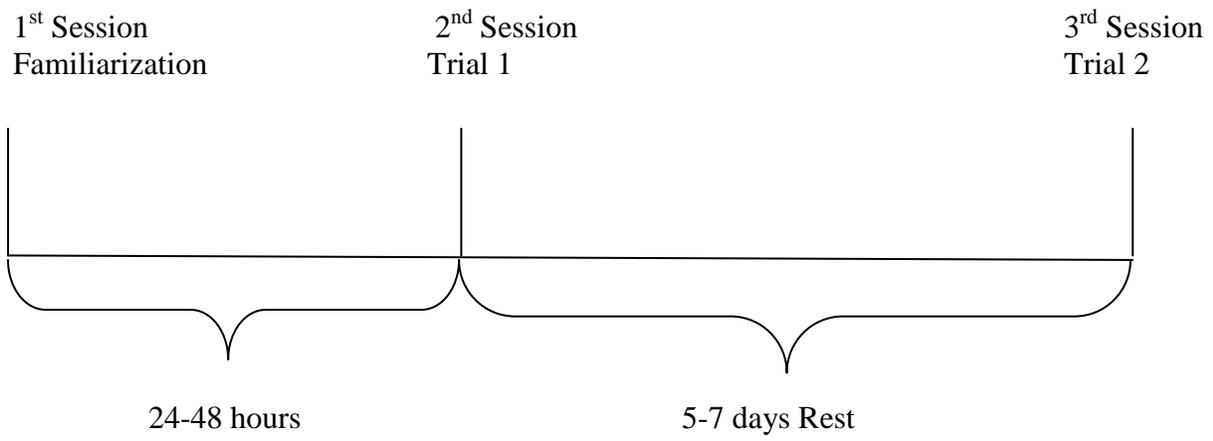


Figure 1.- Study procedures.

### *Simulated Baseball Games*

Participants underwent a simulated 1-inning familiarization to become accustomed to the pace between pitches and innings during each trial, and to the complete testing protocol.

Following the completion of the familiarization inning, a designated time was arranged for the participant to perform subsequent trials. Experimental trials began 48-h after the familiarization session. A minimum five-day and a maximum seven-day rest period separated the two experimental trials to simulate the accepted rest period between starts in baseball. Each experimental trial lasted approximately one hour.

During cooling treatment (AC), participants remained seated with two bags of wetted-ice inside ice wraps (Mueller Sports Medicine Inc, Prairie du Sac, WI). One ice bag was positioned on the shoulder and the other positioned on the forearm. The control treatment (NC) consisted of having the participant sit in a chair. Participants were permitted to drink water ad libitum, though none of the participants chose to drink any fluids. Each pitch was thrown into the same Rawlings Sports Training Net (Rawlings, St. Louis, MO) and pitch velocity was evaluated using a radar gun (Bushnell Outdoor Products, Overland Park, KS). Participants' average pitch speed for each inning as well as over all five innings of both treatment trials were recorded and analyzed. All testing sessions took place outside in a temperate environment ( $18.3 \pm 2.8$  °C;  $49 \pm 4\%$  relative humidity).(Figure 2)

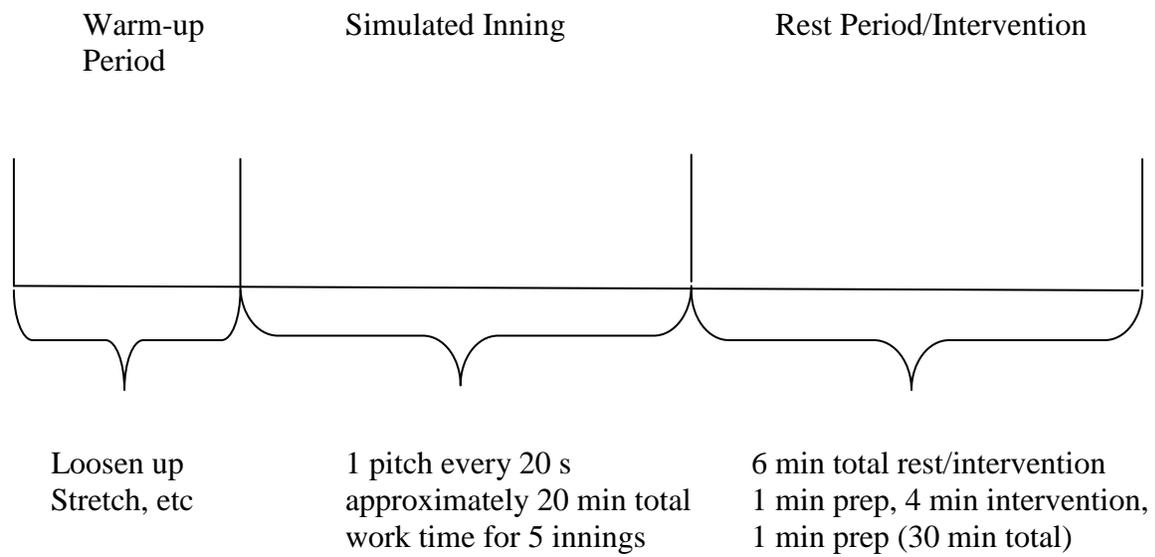


Figure 2. – The simulated-inning design.

### *Data Analyses*

Non-parametric RPE and PRS data were totaled and placed into frequency distribution charts. RPE was then coded into three categories: Light Exertion (6-11), Moderate Exertion (12-14), and Heavy Exertion (15-20). PRS was then coded into three categories: Fully Recovered (10-8), Moderately Recovered (7-6), and Not Recovered (5-3).

### *Statistical Analyses*

Data were analyzed using SPSS v. 20.0 (IBM SPSS Statistics, Somers, NY), with results reported as means  $\pm$  SD. All p-values of less than 0.05 were considered statistically significant. A two-way (treatment x time) repeated measures analysis of variance (ANOVA) was used to test the significance of mean differences for the primary dependent measure of velocity totaled for all innings. In the event of a significant interaction effect, paired samples t-tests were performed to determine differences in means between treatments at specific time points. A non-parametric Wilcoxon signed rank test for related-samples was used to evaluate subjective ratings (RPE, PRS).

## **RESULTS**

A significant interaction was found between treatments AC and NC, with average pitch speed across all innings higher with AC than NC ( $31.2 \pm 2$ ,  $30.6 \pm 2$  m·s<sup>-1</sup>, respectively,  $p = 0.04$ ) (Table 1). A comparison of pitch velocity by inning between the two treatments (Figure 3) resulted in significantly higher mean pitch speeds in the 4<sup>th</sup> inning and 5<sup>th</sup> inning with AC treatment ( $31.3 \pm 2.0$  m·s<sup>-1</sup> and  $31.3 \pm 2.0$  m·s<sup>-1</sup>,  $p = 0.04$ ) compared to NC ( $30.0 \pm 2.2$  m·s<sup>-1</sup> and

$30.4 \pm 2.0 \text{ m}\cdot\text{s}^{-1}$ ), respectively. Subjective measures of RPE and PRS were compared frequency distribution compared. RPE during NC resulting in a distribution of 1 = 20%, 2 = 25%, and 3 = 55%. Results of analyzing PRS distribution showed 1 = 25%, 2 = 55%, and 3 = 20%. Comparisons of AC and NC resulted in significantly lower RPE ( $p \leq 0.01$ ) and improved perceived recovery PRS ( $p \leq 0.01$ ) for AC when compared to NC.

Table 1- Pitching velocity over by inning comparison of arm cooling (AC) and no cooling (NC) treatments. Mean pitch speed reported in meters per second ( $m \cdot s^{-1}$ ). All data are represented in means and SD ( $n = 8$ ).

<b>Inning</b>	<b>NC</b>	<b>AC</b>	<b>p</b>
<b>Mean pitch speed (Cumulative)</b>	30.6 ± 2	31.2 ± 2	0.01
<b>1st inning</b>	31.3 ± 2	31.3 ± 2	0.42
<b>2nd inning</b>	30.8 ± 2	31.3 ± 2	0.24
<b>3th inning</b>	30.4 ± 2	31.3 ± 2	0.07
<b>4th inning</b>	30.0 ± 2	31.3 ± 2	0.01
<b>5th inning</b>	30.4 ± 2	31.3 ± 2	0.02

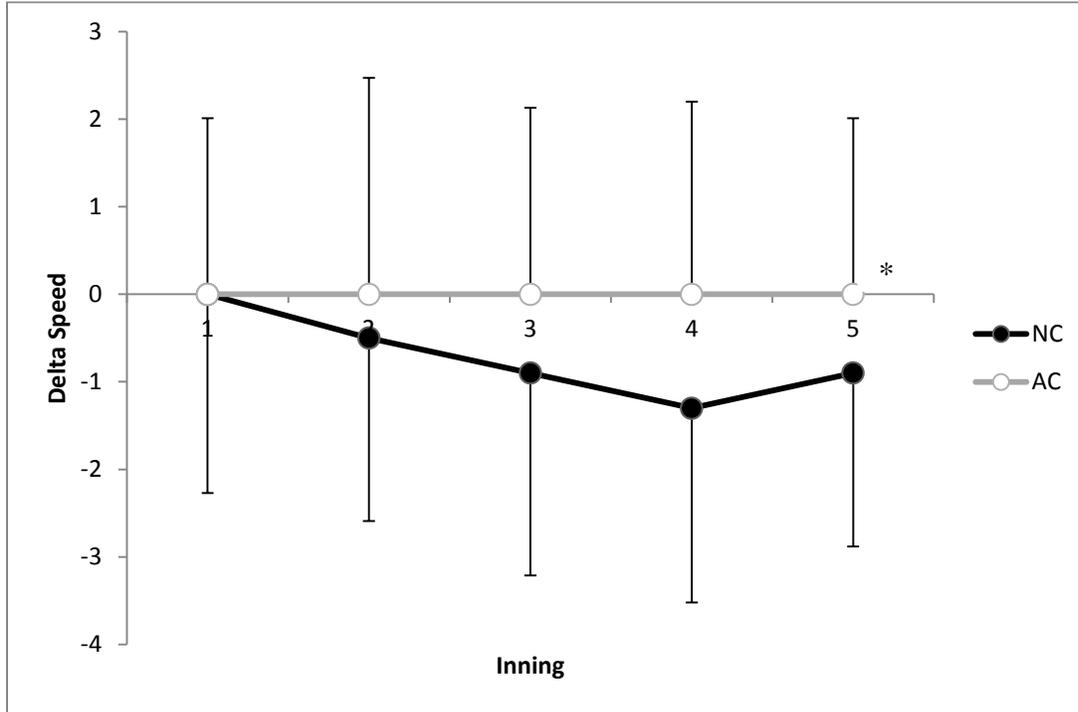


Figure 3- Mean change in pitch velocity for no cooling (NC) and for arm cooling (AC) shown over the five innings ( $n = 8$ ).

Note: \* indicates significant difference ( $p < 0.05$ )

## DISCUSSION

This study examined the effect of 4-min of intermittent cooling of the shoulder and forearm on pitching velocity and the subjective measures of recovery and exertion. Shoulder and forearm cooling between innings attenuated the decrease in pitching velocity when compared to NC, with a mean decrease of 4% ( $p = 0.04$ ) in pitching velocity recorded during NC treatment. AC treatment improved perceived recovery between innings. Comparison of treatments resulted in 35% reduction ( $p = 0.01$ ) in perceived exertion. A comparison of pitch velocity by inning between the two treatments significantly attenuated decreases in mean pitch speed ( $p = .08$ ) in the 4<sup>th</sup> inning and 5<sup>th</sup> inning with AC treatment when compared to NC. These data show that intermittent cryotherapy can attenuate velocity decreases in pitchers late in a baseball game, possibly resulting in improved performance. These findings support those of a previous study (Verducci, 2001) which found that intermittent cooling attenuated decreases in pitching velocity and allowed for increased total work (26% more pitches).

It is well documented that the overhand throwing motion (e.g. baseball pitching) places tremendous stress upon the upper extremity and increases risk for overuse injuries (Atwater et al., 1979; McCue et al., 1985; Litchfield et al., 1993; Fleisig et al., 1995, Altchek et al., 1995; Paley et al., 2000, Burkhart et al., 2000; Park et al., 2003; Olsen et al., 2006). Szymanski (2009) further expressed the potential for injuries related to the repetitive nature of baseball sport's specific activity, in particular, the large forces and torques essential to the overhand throw substantially stresses the shoulder during throwing. Fleisig and colleagues (1995) reported peak torque placed on the throwing elbow reaches the maximum capacity of the ulnar-connective tissue. These stresses lead to micro-trauma in the soft tissues surrounding the elbow and, due to

the repetitive nature of baseball throwing, can result in overuse injuries from the accumulating damage.

Direct comparison of pre-cooling research and pitching cryotherapy modalities share similar results when looking at the subjective exertion, subjective recovery, and pitch velocity. The precise mechanism in which cooling improves performance in comfortable as well as in hot environments is not known. In a 2002 review article on the efficacy of pre-cooling and performance, Marino (2002) examined several strategies evaluating the effect of cryotherapy application and concluded that cold-therapy attenuated decreased performance and improved recovery during repetitive exercise and heat stress.

Research has shown that proper application and duration of cryotherapy is activity specific. Due to the nature of the event or performance, certain applications may not be suitable for competition or recovery. Pre-cooling has been shown to be effective prior to running and cycling (Gabrys et al., 1993; Marsh and Sleivert, 1999; De Pauw et al., 2011; Ross et al., 2010; Boothe et al., 2001; Hunter et al., 2004; Tegeder et al., 2008; Arngrimmson et al., 2004; Price et al., 2009), while interval cooling has been shown to help in repeated performance (Verducci 2000; 2001) and post-bout strength and recovery (Yanagisawa et al., 2003).

Cold-therapy is also shown to reduce the perceptions of exertion during exercise in the heat as well. Cryotherapy is reported to reduce the sensation of pain, inflammation, and the biomarkers associated with overuse (Beelen et al., 1991; Burgess and Lambert 2010). In our study, AC significantly attenuated a decrease in velocity over five innings of simulated play resulting in significantly lower perceived exertion during baseball pitching. Subjective recovery was significantly improved during the AC treatment between innings when compared to NC.

The effects of pain relief and diminished tissue temperature could explain the attenuated velocity and facilitated recovery with AC.

However, limited research has been published on cryotherapy and pitching performance, with multiple methods and populations being tested. In an earlier study on pre-cooling and pitching, researchers administered 20 min of pre-cooling as well as pre-heating in a temperate environment on non-elite pitchers (Hannan et al., 1997). Results after five innings of pitching showed no significant differences in velocity or pitching performance between treatments. These findings could be attributed to the 20 min of pre-cooling instead of an intermittent application during the trial.

Verducci (2000) applied an intermittent cryotherapy protocol during repeated exercise performance. Verducci applied cooling to the shoulder and forearm between sets of pulls from a weight stack, resulted in significantly greater number of repetitions and total work performed (14.5% more pulls in the cryotherapy group).

In a second study Verducci (2001) applied 3-min of cooling to the shoulder and forearm of non-elite pitchers between innings. Pitchers were asked to report their subjective arm fatigue on a scale of 1-3: 1 = no fatigue, 2 = onset of fatigue, 3 = arm is fatigued. A fatigue rating of 3 resulted in a termination of the pitching trial. Verducci found that the cooling treatment increased the amount of work (22% more pitches) and velocity (1.9 - 4.9%) when compared to the control.

A more recent study by Yanagisawa et al. (2003) examined the effect of five different recovery protocols on maximal baseball pitching performance. Pitchers in this study were asked to throw 98 pitches, or the equivalent of a hypothetical maximal pitching effort. This study found that the cryotherapy alone and cryotherapy combined with light shoulder exercise were the

superior methods to minimizing loss in shoulder strength and maximizing 24-hour subjective recovery. It is important to note that all treatments took place post-bout and did not take place during the performance.

Findings by Verducci (2000; 2001), combined with the present study suggests that intermittent cooling of the shoulder and forearm in between innings is a practical way to provide cold therapy in a baseball setting, providing an ergogenic aid to perceived recovery and attenuated decreases in throwing velocity. With the improvements in perceived recovery, it is conceivable that an athlete may feel they have greater energy and will be able to perform better later in a game. Improved subjective recovery coupled with the physiological effects of cryotherapy could be used to help reduce the occurrences of overuse injuries in athletes (Beelen et al., 1991; Booth et al., 2001; Burgess and Lambert, 2010).

Limitations of this study were that participants were tested in a temperate environment and were not asked to pitch to a hitter. The removal of hitters during this study was thought to limit the confounding effect of accuracy, thereby allowing for maximal exertion during each pitch. Pitch type were also controlled due to the universal nature of the fastball pitch and therefore the more broad inferences of data results.

It is frequently observed that pitchers use warming between innings. The rationale behind this practice is to keep the shoulder and forearm muscles warm between innings. However, pitchers are given ample time to stretch and warm-up prior to each inning. The pitcher's warm-up period is mandatory and helps promote blood flow to the muscles and consequently to the skin. The increase in blood flow to the surface of the body is a direct result of the increased metabolic heat produced from the working muscles and the subsequent response of the body to maintain thermal homeostasis. Conversely, surface cooling is shown to vasoconstrict blood

vessels in the skin, eventually cooling the muscle temperature and attenuating rises in temperature due to excess metabolic heat. Anecdotally, all participants involved in the current study revealed they would choose intermittent cryotherapy as a treatment modality between innings in the tested environment, which was cool relative to many baseball games.

Baseball is an activity that lends itself to cryotherapy due to the intermittent nature of the game. Cooling can take place between innings, providing an opportunity for application before and after activity. Ice therapy is a practical method of cryotherapy in an ecologically valid environment. Future studies should focus on repeated trials of intermittent cooling in simulated-game situations, controlling for pitches as well as ambient temperature. These studies could focus on competitive collegiate, and professional players for greater ecological validity.

## **CONCLUSION**

The findings from this study suggests intermittent cooling of the shoulder and forearm provided a significant improvement in perceived recovery, exertion and pitching velocity during baseball pitching in a temperate environment. The mechanisms responsible for the ergogenic effect of cryotherapy on high-intensity intermittent activity remain to be determined. This practical treatment and the potential positive effects could improve pitching performance and might reduce overuse injuries.

## REFERENCES

- Arngrímsson, Sigurbjorn A, Pettitt, Darby S., Stueck, Matthew G., Jorgensen, Dennis K., Cureton, Kirk J. (2004) Cooling vest worn during active warm-up improves 5-km run performance in the heat. *J Appl Physiol* 96: 1867–1874.
- Altchek DW, Dines DM (1995) Shoulder injuries in the throwing athlete. *J Am Acad Ortho Surg* 3:159-165.
- Atwater AE. (1979) Biomechanics of overarm throwing movements and of throwing injuries. *Exerc Sport Sc. Rev* 7: 43- 85.
- Bailey DM, Erith SJ, Griffin PJ, Dowson A, Brewer DS, Gant N, Williams C. (2007) Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. *J Sports Sci* 25(11): 1163-1170.
- Beelen, A Sargeant, AJ. (1991) Effect of lowered muscle temperature on the physiological response to exercise in men. *Eur J Appl Physiol Occup Physiol* 63 (5). 387-392.
- Booth J, Wilsmore BR, Macdonald AD, Zeyl A, Mcghee S, Calvert D, Marino FE, Storlien LH, Taylor NAS. (2001) Whole-body pre-cooling does not alter human muscle metabolism during sub-maximal exercise in the heat. *Eur J Appl Physiol* 84: 587-590.
- Burgess TL, Lambert MI. (2010) The efficacy of cryotherapy on recovery following exercise-induced muscle damage. *Intern Sports Med J* 11(2): 258-277.
- Burkhart SS, Morgan CD, Kibler WB. (2000) Shoulder injuries in overhead athletes: The “dead arm” revisited. *Clin Sports Med* 19:125-158.
- Castle, Paul C., Adam L. Macdonald, Andrew Philp, Anthony Webborn, Peter W. Watt, and Neil S. Maxwell. (2006) Pre-cooling leg muscle improves intermittent sprint exercise performance in hot, humid conditions. *J Appl Physiol* 100: 1377–1384.
- Cheung SS, Reynolds LF, Macdonald MA, Tweedie CL, Urquhart RL, Westwood DA. (2008) Effects of local and core body temperature on grip force modulation during movement-induced load force fluctuations. *Eur. J. Appl. Physiol.* 103: 59-69.
- Clarke ND, Maclaren DPM, Reilly T, Drust B. (2011) Carbohydrate ingestion and pre-cooling improves exercise capacity following soccer-specific intermittent exercise performed in the heat. *Eur. J. Appl. Physiol.* 111:1447–1455.
- De Pauw, K, De Geus, B, Roelands, B, Lauwens, F, Verschueren, J, Heyman, E, Meeusen, Romain R. (2011) Effect of five different recovery methods on repeated cycle performance. *Med Sci Sports Exerc* 43(5): 890-897.

- Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. (1995) Kinetics of baseball pitching with implications about injury mechanisms. *Am. J. Sports Med.* 23(2):233-239.
- Gabrys, J. Pieniasek, W. Olejnik, I. Pogorzelska, T. Karpe, J. (1993) Effects of local cooling of neck on circulatory responses in men subjected to physical exercise in hyperthermia. *Biol. Sport.* 10 (3): 167-171.
- Goodall S, Howatson G. (2008) The effects of multiple cold-water immersions on indices of muscle damage. *J Sports Sci Med* 7: 235-241.
- Hannan RL, Margarucci KD, Merkovsky SM, Knight KL, Ingersoll CD, Edwards JE. (1997) Effects Of Cooling And Heating The Shoulder On Pitching Velocity And Accuracy. *J Athl Train* 32(2).
- Halvorson GA. (1990) Therapeutic heat and cold for athletic injuries. *Phys Sportsmed* 18(5):87-92, 94.
- Howatson G, van Someren KA. (2008) The Prevention and treatment of exercise-induced muscle damage. *Sports Med.* 38(6): 483-503.
- Hunter L, Hopkins TJ, Casa DJ. (2006) Warming up With an Ice Vest: Core body Temperature Before and After Cross-Country Racing. *J Athl Train* 41:371-374.
- Litchfield R, Hawkins R, Dillman CJ. (1993) Rehabilitation of the overhead athlete. *J Ortho Sports Phys Ther* 18:433-441.
- Lyman S, Fleisig GS, Waterbor JW. (2001) Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med. Sci. Sports Exerc.*33:1803-1810.
- Knight KL. *Cryotherapy in Sport Injury Management*. Champaign, IL: Human Kinetics, 1995. Pp. 65-67, 68, 130-132.
- Marino FE. (2001) Methods, advantages, and limitations of body cooling for exercise performance. *Br. J. Sports Med.* 36: 89-94.
- Marsh D, Sleivert G. (1999) Effect of pre-cooling on high intensity cycling performance. *Br. J. Sports Med.* 33:393-7.
- Matsuo T, Matsumoto T, Mochizuki, Y, Takada Y, Saito K. (2002) Optimal Shoulder Abduction Angles during baseball pitching from maximal wrist velocity and minimal kinetics viewpoints. *J. Appl. Biomech.* (18): 306-320.
- McCue FC, Gieck JH, West JO. *Injuries to the Throwing Arm*. Philadelphia, PA: W.B. Saunders Co, 1985. pp. 95-111.
- McMaster WC. (1982) Cryotherapy. *Phys. Sportsmed.* 10(11):112-119.

- Olsen, SJ, Fleisig GS, Shouchen D, Loftice J, Andrews JR. (2006) Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *Am. J. Sports Med.* 34(6). 905-912.
- Park SS, Loebenberg ML, Rokito AS, Zuckerman JD. (2002) The shoulder in baseball pitching: biomechanics and related injuries Part 1. *Hosp. Joint Dis.* 61(1). 80-88.
- Paley KJ, Jobe FW, Pink MM. (2000) Arthroscopic findings in the overhand throwing athlete: Evidence for posterior internal impingement of the rotator cuff. *Arthroscopy* 16:35-40.
- Pietrosimone BG, Hart JM, Ingersoll CD. (2009) Effects of focal knee joint cooling on spectral properties of rectus femoris and vastus lateralis electromyography. *Athl. Train. Sports Health Care.* 1(4). 154-161.
- Piedrahita, H, Oksa, J, Rintamäki, H, Malm, C. (2009) Effect of local leg cooling on upper limb trajectories and muscle function and whole body dynamic balance. *Eur. J. Appl. Phys.* 105 (3): 429-438.
- Price MJ, Boyd C, Goosey-Tolfrey VL. (2009) The physiological effects of pre-event and mid-event cooling during intermittent running in the heat in elite female soccer players. *Appl. Physiol. Nutr. Metab.* 34: 942–949.
- Reilly T, Ekblom B. (2005) The use of recovery methods post-exercise. *J. Sports Sci.* 23(6): 619-627.
- Ross, M L. R. Garvican, L A. Jeacocke, N A.<sup>1</sup>Laursen, P B. Abbiss, C R. Martin, D T. Burke, L M. (2011) Novel pre-cooling strategy enhances time trial cycling in the heat. *Med. Sci. Sports Exer.* 43(1): 123-133.
- Snyder JG, Ambegaonkar JP, Winchester JB. (2011) Cryotherapy for treatment of delayed onset muscle soreness. *Inter. J. Athl. Ther. Train* 16(4): 28-32.
- Szymanski, DJ. (2009) Physiology of baseball pitching dictates specific exercise intensity for conditioning. *Strength Cond. J.* 31(2).
- Tegeder AR, Hunter I, Mack GW, Hager R. (2008) Long-distance interval training following pre-cooling with an ice vest. *Inter. J. Sports Sci. Coach*: 3(2).
- Thorsson, O. Lilja, B. Ahlgren, L. Hemdal, B. Westlin, N. (1985) The effect of local cold application on intramuscular blood flow at rest and after running. *Med. Sci. Sports Exer.* 17 (6): 710-713.
- Utsunomiya, M, Nitta, K, Sawagichi, H, Yoshikawa, A, Karasuno, H, Morozumi, K, Allison, GT, Fujiwara, T., Abe, K. (2010) Changes in blood flow, temperature and muscle endurance in association with cryotherapy. *J. Phys. Ther. Sci.* 22 (1): 43.

Vaile J, O'Hagan C, Stefanovic B. (2010) Effect of cold-water immersion on repeated cycling performance and limb blood flow. *Br. J. Sports Med.* 45(10): 825-829.

Verducci FM. (2000) Interval cryotherapy decreases fatigue during repeated weight training. *J. Athl. Train.* 35(4): 422-426.

Verducci FM. (2001) Interval cryotherapy and fatigue in university baseball pitchers. *Res. Q. Exerc. Sport* 72(3): 280-287.

Wassinger CA, Myers JB, Gatti JM, Conley KM, Lephart SM. (2007) Proprioception and throwing accuracy in the dominant shoulder after cryotherapy. *J. Athl. Train.* 42(1):84-89.

Yanagisawa, O, Miyanga, Y, Shiraki, H, Himojo, H, Mukai, N, Niitsu, M, Itai, Y. (2003) The effects of various therapeutic measures on shoulder strength and muscle soreness after baseball pitching. *J. Sports Med. Phys. Fitness* 43: 189-201.

## STUDY II

### THE EFFECT OF INTERMITTENT TORSO COOLING ON THERMOREGULATION AND PERCEIVED RECOVERY IN BASEBALL CATCHERS

#### ABSTRACT

A baseball catcher may have to catch in a hot environment for up to 27 innings over the course of a three-game series. Cryotherapy has been shown to reduce heat and cardiovascular strain during activity in the heat. This study investigated the effects of intermittent cooling of the torso on core temperature ( $T_{re}$ ) and subjective measures of recovery and exertion during a simulated catching performance. Trained college-aged male baseball catchers ( $n = 6$ ) performed simulated catching in a controlled, hot environment (35 °C, 25% relative humidity). Two series of 3-simulated games were used to evaluate heat strain on thermoregulation and mental acuity in baseball catchers; one series with torso cooling (TC) and one with no cooling (NC). Rectal temperature ( $T_{re}$ ), heart rates (HR), perceived exertion (RPE), recovery (PRS) were recorded. A significantly smaller ( $p < 0.01$ ) mean  $T_{re}$  change was seen in TC ( $0.58 \pm 0.2$  °C) when compared to NC ( $0.98 \pm 0.2$  °C). RPE was significantly lower and PRS was significantly improved for TC compared to NC (both  $p \leq 0.05$ ). Mean recovery HR during TC was significantly lower than NC in the 5<sup>th</sup> (TC =  $84 \pm 8$  bpm, NC =  $90 \pm 9$  bpm,  $p = 0.04$ ), 7<sup>th</sup> (TC =  $84 \pm 3$  bpm, NC =  $92 \pm 7$  bpm,  $p = 0.02$ ), and 9<sup>th</sup> (TC =  $85 \pm 7$  bpm, NC =  $93 \pm 5$  bpm,  $p = 0.01$ ) innings. HR during catching was significantly lower at the end of the TC trials when compared to NC ( $108 \pm 16$  bpm versus  $120 \pm 19$  bpm,  $p = 0.02$ ). TC alleviated heat strain, cardiovascular strain, and facilitated perceived recovery in catchers over a simulated three game series performed in hot conditions.

**Key Words:** cryotherapy, core temperature, vest, fatigue, exertion

## INTRODUCTION

Hot and humid environments can substantially impair exercise performance and exercise capacity (Tyler and Sunderland 2008) compared to moderate temperature environments (Galloway and Maughan 1997; Tyler and Sunderland 2008; Lafrenz 2008). One countermeasure to these effects of heat on the body may be intermittent body cooling during athletic performances. For example, pre-cooling increases heat tolerance time, blunts core temperature increases, and decreases subjective measures of effort (RPE) and thermal comfort (RTC) (Arngrimsson et al., 2004; Castle et al., 2006; Hunter et al., 2006; Tyler et al., 2010).

A few studies have investigated the effect of cooling while performing an active warm-up before exercise. Cooling during warm-up for 5 km running while wearing an ice vest blunted the exercise-induced rise in core temperature and heart rate (HR), decreased time to completion, and lowered perceptual measures when compared to a control condition (Arngmisson et al., 2004; Hunter et al., 2006).

Despite these positive findings, practical application of the data to baseball catching in the heat has not been examined. The baseball catcher is involved in every pitch thrown during the course of a baseball game. Catchers in the southern United States are asked to perform these tasks in hot and humid environments. However, the extent to which muscle cooling influences core temperature, perceived exertion and subjective recovery when utilized intermittently during a simulated baseball game in the heat is unknown.

The game of baseball is divided into innings; therefore, intermittent cooling is practical for application during a baseball performance. Therefore, the purpose of this study was to determine if using a vest to cool the torso between innings during a simulated catching

performance in the heat would attenuate the rise in core temperature, improve subjective exertion, and improve the perception of recovery.

## **METHODS**

### *Participants*

Six healthy, competitively-trained male baseball catchers were recruited from local baseball programs as well as a local University Club Baseball team ( $n = 6$ ;  $23 \pm 4$  years,  $75.5 \pm 9.8$  kg). All participants had prior catching experience before beginning the study. Participants were also required to throw two or more times per week for  $> 20$  minutes for a minimum of 6 weeks prior to the study. The study was approved by the local Institutional Review Board. Before the study, all participants provided written informed consent.

### *Research design*

A counterbalanced, repeated measures design was used. This study consisted of seven total sessions. Each counterbalanced sequence was randomly assigned to participants. Exercise sessions were held at the same time of day for each participant to avoid circadian variations in core body temperature. Participants entered an environmental chamber maintained at  $35\text{ }^{\circ}\text{C}$ , and relative humidity of 25%. Upon arrival, urine specific gravity (USG) was collected to ensure that participants were adequately hydrated ( $\text{USG} \leq 1.020$ ) prior to each session. Afterward, participants were measured for nude body weight using a digital scale (Tanita Corporation, Tokyo, Japan) prior to each trial.

Participants were familiarized with the protocol by entering the heat chamber and performing one-inning of the testing sequence. The 1-inning familiarization allowed participants

to become accustomed to the time between receiving each pitch. Following completion of protocol familiarization, participants completed six simulated games. The first three simulated-game sessions took place within a 72-hour period, with one session every 24 hours. Upon completion of the first simulated 3-game series, a 7-day rest period followed. Following the rest period, the final three sessions were completed. During each 3-game trial, one of two treatments was used: 1) 6-minutes of recovery (four minutes of vest cooling (TC) of the torso) between each completed half-inning, 2) six minutes sitting with no cooling (NC). Treatment order was randomly assigned and counterbalanced.

### *Measurements*

Rectal temperature ( $T_{re}$ ) was measured using a thermocouple interfaced with a thermocouple meter (Omega HH-20A, Omega Engineering INC, Stamford, CT) before and after each simulated inning. The rectal probe was securely taped to the gluteus maximus under the waistband of the shorts. Heart rate (HR) was monitored using a Polar telemetry transmitter unit (Team Polar, Stamford, CT) and recorded after each inning (working HR) and post-treatment (recovery HR). The Borg 6-20 rating of perceived exertion (RPE) (Borg, 1982) was recorded before each session and at the end of each half inning. The perceived recovery scale (PRS) (Laurent et al., 2011) was recorded before each simulated game and post-treatment each inning. The RPE scale is a 6-20 scalar representation of subjective exertion level. A “6” represents no exertion, and a “20” represents maximal exertion. A “0” on the PRS scale represents no recovery, while a “10” represents full recovery.

## *Procedures*

All trials were conducted in a heated environmental chamber (35 °C, RH 23 ± 2%). The catching cadence consisted of one pitch every 20 s (Yanagisawa et al., 2003). Participants dressed in the same baseball uniform every trial, which consisted of their issued baseball pants, cotton practice shirt, socks, shoes and catching equipment (shin guards, chest protector, helmet and catcher's mask). Thereafter, participants inserted a flexible rectal thermocouple (model RET-1, Physitemp, Clifton, NJ) approximately 8 cm past the anal sphincter. All experimental sessions (individual games) were separated by 24 h.

During the cooling protocol, participants wore a modified reflective ice vest (TC) around the torso (Ironman<sup>®</sup> World Endurance Sports LLC, Tampa, FL) for 4-min and were allowed to rest seated in a chair. The control group sat in a chair, receiving no cooling treatment (NC). Participants were not permitted to drink water ad libitum.

Participants received 12 simulated pitches during the work period of each inning, which equated to one pitch every 20 s. A test administrator delivered all simulated pitches from a point approximately 3.5 m from the participant. The participant received each pitch in the squatting position while wearing full catching gear, and proceeded to simulate a throw to the pitcher by standing and throwing back to the test administrator approximately 3.5 m in front of them. Before each pitch, participants returned to the squatting position to receive the next pitch. After all pitches were received, participants' simulated sitting in the dugout by sitting quietly in the chamber and removing their helmet, mask, and chest protector. The chest protector was replaced with the ice vest treatment for one trial.

### *Data Analyses*

Subjective measurements (RPE, PRS) were totaled and measured for frequency with a distribution chart. Frequency distribution of PRS data was placed into two categories: 10 - 8 = Recovered and 7 - 5 = Not Recovered. Frequency distribution of RPE data was placed into three categories: 7 - 8 = Low Exertion, 9 - 10 = Moderate Exertion and 11 - 12 = Heavy Exertion.

### *Statistical Analyses*

All data are presented as mean  $\pm$  SD. Rectal temperature data were analyzed using a two-way repeated measures analysis of variance (ANOVA) to test the significance of mean differences among treatment conditions (before and after each inning and each game). In the event of a significant interaction effect, paired samples t-tests were performed to determine differences in means between treatments at specific time points. As non-parametric data, frequency distributions were analyzed for subjective measures (PRS, RPE). Both subjective measures were re-coded and evaluated by a related-samples Wilcoxon signed-rank test. Data were analyzed using SPSS v. 20 (SPSS, Inc., Chicago, IL). All p-values of less than 0.05 were considered statistically significant.

## **RESULTS**

### *Physiological Measures*

A significant interaction was seen ( $p = 0.05$ ) between treatments in overall mean  $T_{re}$  and working HR (Figure 1) over the three-game series. A significantly smaller ( $p < 0.05$ ) rise in  $T_{re}$  was seen in the TC compared NC (NC =  $0.98 \pm 0.2$  °C, TC =  $0.58 \pm 0.2$  °C,  $p = \leq 0.01$ ) for the

mean of the three game series simulation. There were significant differences in mean change in rectal temperature in each of the three simulated games (Game 1;  $p \leq 0.01$ , Game 2;  $p = 0.02$ ; Game 3,  $p < 0.01$ ) (Figure 2). Significantly lower mean recovery heart rates of all games were found during TC treatment when compared to NC in the 5<sup>th</sup> (TC =  $84 \pm 8$  bpm, NC =  $90 \pm 9$  bpm,  $p = 0.04$ ), 7<sup>th</sup> (TC =  $84 \pm 3$  bpm, NC =  $92 \pm 7$  bpm,  $p = 0.02$ ), and 9<sup>th</sup> (TC =  $85 \pm 7$  bpm, NC =  $93 \pm 5$  bpm,  $p = 0.01$ ) innings. Mean working HR for the three game series was significantly lower during the TC treatment in the 9<sup>th</sup> inning when compared to the control (TC =  $108 \pm 16$  bpm, NC =  $120 \pm 19$  bpm,  $p = 0.01$ ) (Table 1).

### *Subjective Measures*

A significantly lower perceived exertion ( $p \leq 0.01$ ) and improved perceived recovery ( $p \leq 0.01$ ) with the torso cooling treatment compared to control for the three game series. Percent of categorical responses for RPE during NC results: 1 = 32.5%, 2 = 35.6%, 3 = 31.9%. Percent of categorical responses for RPE during TC results: 1 = 38.3%, 48.8%, 3 = 13.0%. Percent of categorical responses for PRS during NC results: 1 = 56.3%, 2 = 43.8%. Percent of categorical responses for PRS during TC results: 1 = 31.5%, 2 = 68.5%

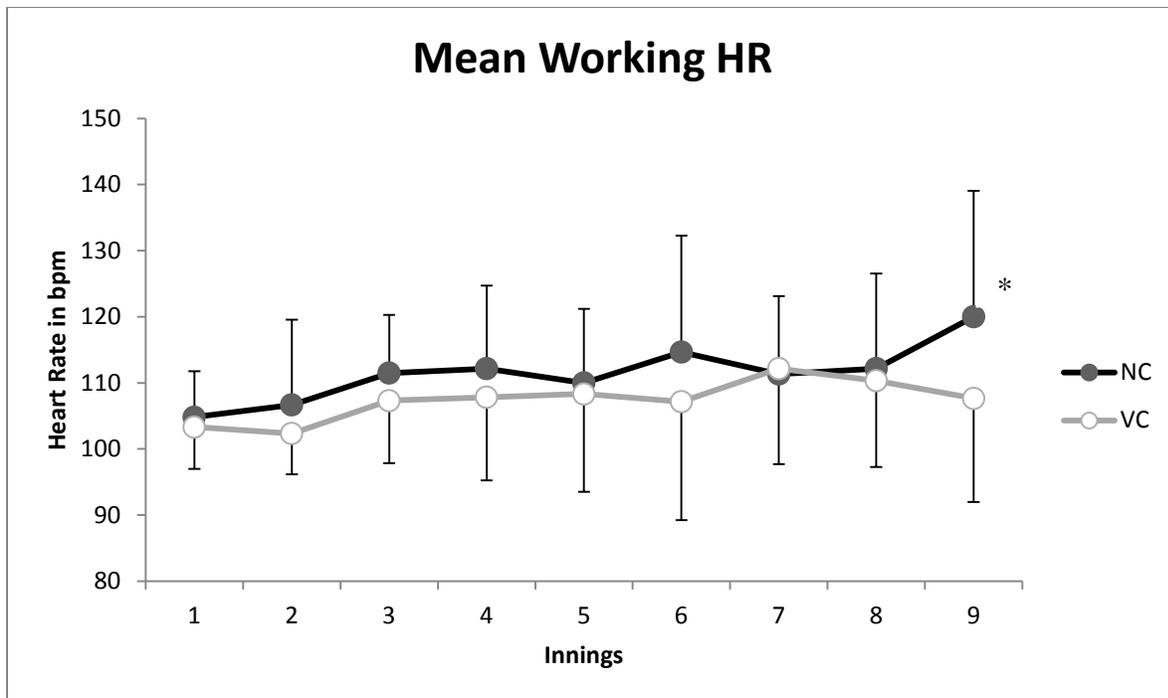


Figure 1- Working HR recorded and averaged over all simulated games. Results of each treatment were compared ( $n = 6$ ). Mean working HR was significantly lower at the end of the three game series for the torso cooling (TC) treatment when compared to control (NC).

Note: \* represents a significant differences.

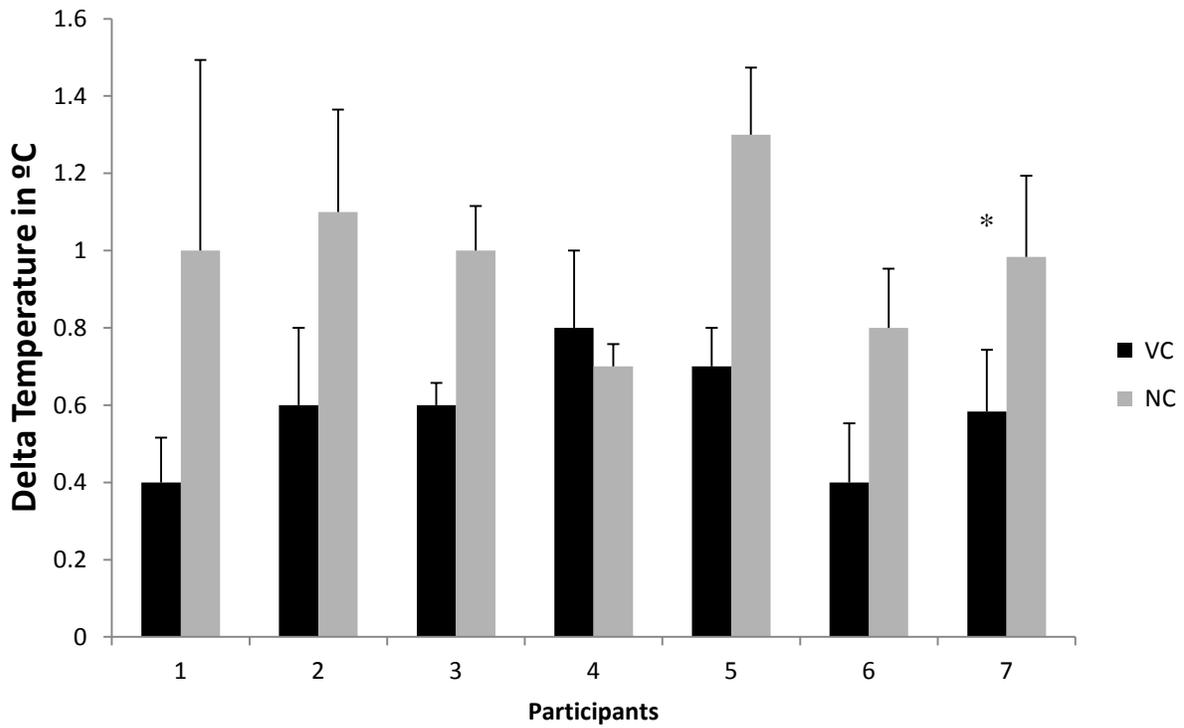


Figure 1. - All data represented as mean and SD.  $T_{re}$  change over the course of the three-game series. The 1-6 on the x-axis represents the six subjects mean  $T_{re}$ , comparing torso cooling (TC) and control (NC). Number 7 represents the mean temperature change of all participants combined. Note: \* represents a significant differences.

Table 1. - Dependant variables of recovery HR and working HR, comparing control (NC) versus torso cooling (TC). Heart rate measured in beats per minute (bpm) ( $n= 6$ ).

<b>Dependent Variables</b>	<b>NC</b>	<b>TC</b>	<b>p</b>
<b>Mean Working HR</b>	112 $\pm$ 4	107 $\pm$ 3	0.01
<b>Recovery HR 5th Inning</b>	90 $\pm$ 9	84 $\pm$ 8	0.04
<b>Recovery HR 7th Inning</b>	92 $\pm$ 7	84 $\pm$ 3	0.02
<b>Recovery HR 9th Inning</b>	93 $\pm$ 5	85 $\pm$ 7	0.01
<b>Working HR 5th Inning</b>	110 $\pm$ 11	108 $\pm$ 15	0.27
<b>Working HR 7th Inning</b>	111 $\pm$ 12	112 $\pm$ 15	0.37
<b>Working HR 9th Inning</b>	120 $\pm$ 19	108 $\pm$ 16	0.01

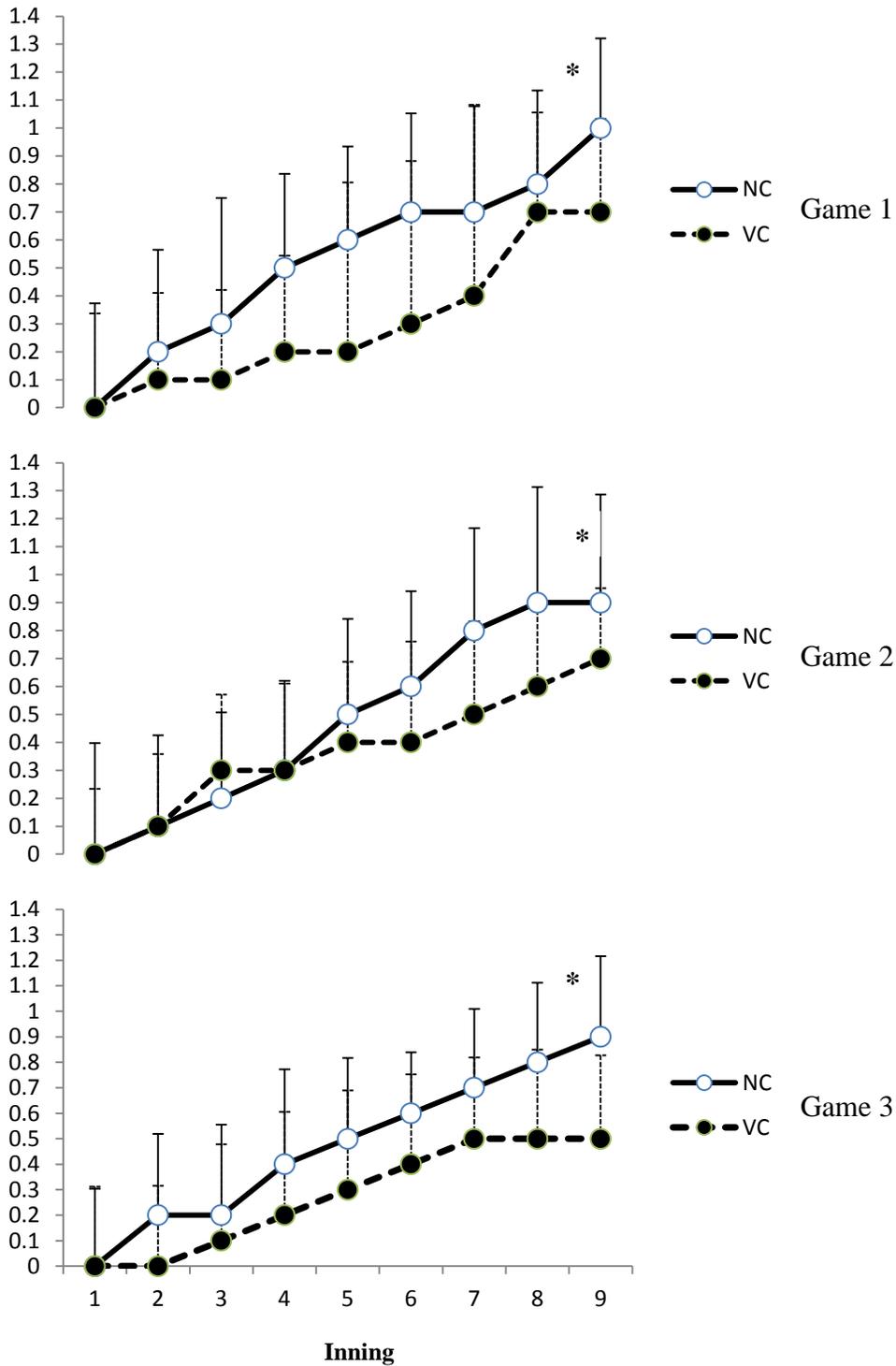


Figure 2. – Mean delta rectal temperature (°C) comparisons by treatment and simulated game. Control (NC) versus torso cooling (TC) ( $n=6$ ).  
 Note: \* denotes significant difference.

## DISCUSSION

The current study examined 4-min of torso cooling between innings, examining the effect on  $T_{re}$ , RPE, and PRS. We found that torso cooling significantly attenuated the rise in core temperature during simulated catching performance in the heat. There were significant lower mean  $T_{re}$  and recovery heart rates during the TC treatment in the 5<sup>th</sup>, 7<sup>th</sup> and 9<sup>th</sup> innings. The 5<sup>th</sup> inning comparison represents the fewest innings played during a high school game prior to weather delays or mercy rules. The 5<sup>th</sup> inning is also the minimum innings needed to be completed to be awarded a win in Major League Baseball (MLB). The 7<sup>th</sup> inning comparison corresponds with the total innings played during a complete college-level game. The 9<sup>th</sup> inning comparison corresponds with a complete game of innings played during a professional game. The lower rise in  $T_{re}$  indicates reduced thermal strain, and the lower resting HR indicates reduced cardiovascular strain.

Results of this study support previous studies suggest that reducing core temperature before exercise can lower thermal and cardiovascular strain, resulting in more work performed before a critical temperature is reached (Marino, 2002). Our findings support Marino's (2002) review of pre-cooling and intermittent cooling efficacy on performance and similar protocols tested in baseball (Verducci 2001; Yanagisawa et al. 2003). Marino (2002) examined several strategies evaluating the effect of cryotherapy to alleviate reductions in performance and improve recovery during exercise and heat stress. Verducci (2001) examined the effect of intermittent cooling on velocity and total work done in non-elite pitchers, citing the cooling group had an increase in work as well as velocity when compared to the control.

The mechanism in which pre-cooling improves performance in hot environments remains unclear. The currently accepted cryotherapy protocols depend on a number of factors. The

duration of pre-cooling is generally 20 minutes (Hannan et al. 1997), subtracting or adding time depending on the modality and activity-specific application (Verducci 2000, 2001; Yanagisawa 2003). However, we found that just 4 minutes of intermittent cooling significantly blunted core temperature increases as well as reduce cardiovascular strain over simulated 3-game baseball series.

To our knowledge, this is the first study to look at the effects of intermittent torso cooling on core temperature and the first on catchers. Baseball is an activity that lends itself to an intermittent cold-therapy protocol due to the interval nature of the game. Cooling can take place in between innings, providing an opportunity for application before and after activity in the heat. Cold applications result in an immediate and rapid decline in surface skin temperature (Knight 1985, 1995; Myrer et al. 1997, 1998; Ray et al., 1997). These temperatures initially decrease sharply, and gradually plateau over time. Research (Knight 1995; Merrick et al., 1993), found that three minutes of cryotherapy had no effect on muscle temperature whereas Waylonis (1967) indicated that after five minutes of ice massage resulted in significant decreases in muscle temperature. These findings provided a rationale for application of 4-min of cold therapy between innings. Our results suggest that 4-minutes of cryotherapy produce an effect of reduced thermal strain with repeated applications over time.

The observed benefits of intermittent cryotherapy during baseball catching in the heat are supported in other research. Cryotherapy is often used for its effect on intramuscular tissues (Bender et al., 2005; Burgess et al., 2010), and pain reduction (Bleakley et al., 2004) by causing vasoconstriction and cellular metabolism reduction. This reduction in cellular metabolism is thought to help produce a subsequent decrease in metabolic heat as well as reduce overuse injuries (Burgess et al., 2010), though the results are inconclusive. Many studies have

investigated local muscle cooling and the positive effect on multiple performance variables (Barnes et al., 1985; Gabrys et al., 1993, Marsh and Sleivert, 1999; De Pauw et al., 2011; Ross et al., 2010; Castle et al., 2005; Piedrahita et al 2008, Pietrosimone et al., 2009), including cycling time-trial duration and 5-kilometer run time. Results of these studies support the use of cryotherapy as an ergogenic aid for sports and exercise performance.

In our study, the increases in  $T_{re}$ , and HR during baseball catching were blunted by wearing the cooling vest when compared to the control. Perceptions of recovery and exertion with the intermittent cryotherapy treatment were also significantly lower compared to control. This supports studies showing that cooling reduces perceived exertion and appears to improve recovery in exercise (Gabrys et al. 1993; Marsh and Sleivert 1999; Boothe et al. 2001, Hunter et al. 2004; Arngrimmson et al. 2004; Tegeder et al. 2008; Price et al. 2009; Ross et al. 2010; De Pauw et al. 2011) and other intermittent activity (Verducci 2000; 2001). However, it should be noted that the tested protocol simulated the best-case scenario for baseball catching in the heat. Catchers were not asked to simulate batting or running the bases. Hitting and base running are skills required of a catcher and may be performed over the course of a game, and would add to the metabolic cost of baseball catching. Also, depending on the nature of a particular game, the amount of work (i.e. number of pitches caught) might increase. However, it is doubtful that the amount of ice vest application would be reduced much under 4 min per inning.

The TC seems practical and provides potentially positive effects on core temperature, HR, and subjective measures. Future research should examine the relationship of core and muscular temperatures and skill performance of athletes in simulated or real game conditions. This should

include a modified protocol for catchers, simulating the other activities that a catcher would be required to perform in a game, such as hitting and running the bases.

Baseball is a sport that could practically support repeated application of cold therapy due to the intermittent nature of the game. Cooling can take place in between innings, providing an opportunity for application before and after activity in the heat. Although preliminary results are positive, future research is required to determine any ergogenic effects of applied cold-therapy during baseball games.

## **CONCLUSION**

Intermittent cooling lasting 4-min between innings of a simulated baseball game was shown to significantly blunt the increases in rectal temperature. TC was also found to decrease subjective exertion as well as improve subjective recovery. Results of this study showed that intermittent torso cooling helped lower cardiovascular strain by significantly reducing mean recovery HR between innings and mean working HR in the 9<sup>th</sup> inning. In a hot and humid environment, the lower core temperature could improve perceived recovery, reduce subjective exertion levels, and over the course of a three game series potentially help improve catching performance.

## REFERENCES

- Arngrimsson, Sigurbjorn A, Petitt, Darby S., Stueck, Matthew G., Jorgensen, Dennis K., Cureton, Kirk J. (2004) Cooling vest worn during active warm-up improves 5-km run performance in the heat. *J Appl Physiol* 96: 1867–1874.
- Bailey DM, Erith SJ, Griffin PJ, Dowson A, Brewer DS, Gant N, Williams C. (2007) Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. *J of Sports Sci.* 25(11): 1163-1170.
- Barnes, WS. Larson, MR., Effects of localized hyper- and hypothermia on maximal isometric grip strength. *American Journal of Physical Medicine:* 64 (6). 305-314, 1985.
- Bleakley C, McDonough S, MacAuley D. (2004) The Use of ice in the treatment of acute Soft-Tissue Injury. *Amer J Sports Med* 32(1). 251-261.
- Booth J, Wilsmore BR, Macdonald AD, Zeyl A, Mcghee S, Calvert D, Marino FE, Storlien LH, Taylor NAS. (2001) Whole-body pre-cooling does not alter human muscle metabolism during sub-maximal exercise in the heat. *Eur J Appl Physiol* 84: 587-590.
- Burgess TL, Lambert MI. (2010) The Efficacy of cryotherapy on recovery following exercise-induced muscle damage. *International Sports Medicine Journal* 11(2): 258-277.
- Cheung SS, Reynolds LF, Macdonald MA, Tweedie CL, Urquhart RL, Westwood DA. (2008) Effects of local and core body temperature on grip force modulation during movement-induced load force fluctuations. *Eur J Appl Physiol* 103: 59-69.
- Castle, PC, Macdonald, Adam L, Philip, A, Webborn, A, Watt, P and Maxwell, NS (2006) Precooling leg muscle improves intermittent sprint exercise performance in hot, humid conditions. *J Appl Physiol* 100: 1377–1384.
- De Pauw, K, De Geus, B, Roelands, B, Lauwens, F, Verschueren, J, Heyman, E, Meeusen, Romain R. (2011) Effect of Five Different Recovery Methods on Repeated Cycle Performance. *Medicine & Science in Sports & Exercise* 43(5): 890-897.
- Galloway, S.D.R. Shirreffs, S.M. Leiper, J.B. Maughan, R.J. (1997) Exercise in the heat: factors limiting exercise capacity and methods for improving heat tolerance. *Sports Exercise & Injury* 3(1): 19-24.
- Gabrys, J, Pieniasek, W, Olejnik, I, Pogorzelska, T, Karpe, J. (1993) Effects of local cooling of neck on circulatory responses in men subjected to physical exercise in hyperthermia. *Biology of Sport* 10 (3): 167-171.
- Halvorson GA. (1990) Therapeutic heat and cold for athletic injuries. *Physician Sportsmed* 18(5):87–92, 94.

Hunter L, Hopkins TJ, Casa DJ. (2006) Warming up With an Ice Vest: Core body Temperature Before and After Cross-Country Racing. *Journal of Athletic Training* 41:371-374.

Lafrenz AJ, Wingo JE, Ganio MS, Cureton KJ. (2008) Effect of ambient temperature on cardiovascular drift and maximal oxygen uptake. *Med. Sci. Sports Exerc* 40:1065-1071.

Knight KL. *Cryotherapy in Sport Injury Management*. Champaign, IL: Human Kinetics 1995: 9,65–67,68,130–132.

Laurent CM, Green JM, Bishop PA, Sjokvist J, Schumacker RE, Richardson MT, Curtner-Smith M. (2011) A Practical Approach to Monitoring Recovery: Development of a Perceived Recovery Status Scale. *J Strength and Cond Res* 25(3): 620-628.

Marino FE. (2002) Methods, advantages, and limitations of body cooling for exercise performance. *Br J Sports Med* 36: 89–94.

Marsh D, Sleivert G. (1999) Effect of pre-cooling on high intensity cycling performance. *Br J Sports Med* 33:393–7.

McMaster WC. (1982) Cryotherapy. *Physician Sportsmed* 10(11):112–119.

Myrer JW, Measom G, Durrant E, Fellingham GW. (1997) Cold and Hot-Pack Contrast Therapy: Subcutaneous and Intramuscular Temperature Change. *J AthlTrain.* 32(3).

Piedrahita, H, Oksa, J, Rintamäki, H, Malm, C. (2009) Effect of local leg cooling on upper limb trajectories and muscle function and whole body dynamic balance. *European Journal of Applied Physiology* 105 (3). 429-438.

Pietrosimone BG, Hart JM, Ingersoll CD. (2009) Effects of local knee joint cooling on spectral properties of rectus femoris and vastus lateralis electromyography. *Athletic Training and Sports Health Care.* 1(4).154-161.

Price MJ, Boyd C, Goosey-Tolfrey VL. (2009) The physiological effects of pre-event and mid-event cooling during intermittent running in the heat in elite female soccer players. *Appl. Physiol. Nutr. Metab.* 34: 942–949.

Ray CA, Hume KM, Gracey KH, Mahoney ET. (1997) Muscle cooling delays activation of the muscle metaboreflex in humans. *American Journal of Physiology*, 273, 2436-41.

Reilly T, Ekblom B. (2005) The Use of Recovery Methods Post-Exercise. *J Sports Sci.* 23(6): 619-27.

Ross, M L. R. Garvican, L A. Jeacocke, N A.<sup>1</sup>Laursen, P B. Abbiss, C R. Martin, D T. Burke, L M. (2011) Novel Pre-cooling Strategy Enhances Time Trial Cycling in the Heat. *Med Science in Sports & Exercise* 43(1): 123.

Snyder JG, Ambegaonkar JP, Winchester JB. (2011) Cryotherapy for Treatment of Delayed Onset Muscle Soreness. *International Journal of Athletic Therapy and Training* 16(4): 28-32.

Stubblefield ZM, Clearly MA, Garvey SE, Eberman LE (2006). Effects of active hyperthermia on cognitive performance. Proceedings of the Fifth Annual College of Education Research Conference: 1:25-50.

Tegeder AR, Hunter I, Mack GW, Hager R. (2008) Long-Distance Interval Training Following Pre-Cooling With an Ice Vest. *International Journal of Sports Science & Coaching* 3(2). 269-278.

Tyler CJ, Wild P, Sunderland, C. (2010) Practical neck cooling and time-trial running performance in a hot environment. *Eur J Appl Physiol* 110:1063-1074.

Utsunomiya, M, Nitta, K, Sawagichi, H, Yoshikawa, A, Karasuno, H, Morozumi, K, Allison, GT, Fujiwara, T., Abe, K. (2010) Changes in Blood Flow, Temperature and Muscle Endurance in Association with Cryotherapy. *J Phys Ther Sci* 22 (1): 43-49.

Vaile J, O'Hagan C, Stefanovic B. (2010) Effect of cold water immersion on repeated cycling performance and limb blood flow. *Br J Sports Me.* 825-829.

Verducci FM. (2001) Interval Cryotherapy and Fatigue in University Baseball Pitchers. *Res Q Exer Sport* 72(3): 280-287.

Verducci FM. (2000) Interval Cryotherapy Decreases Fatigue during Repeated Weight Training. *J Athl Train* 35(4): 422-426.

Waylonis GW. (1967) The Physiologic Effects of Ice Massage. *Arch Phys Med Rehabil* 48(1): 37-42.

Yanagisawa, O, Miyanga, Y, Shiraki, H, Himojo, H, Mukai, N, Niitsu, M, Itai, Y. (2003) The effects of various therapeutic measures on shoulder strength and muscle soreness after baseball pitching. *J Sports Med Phys Fitness* 43: 189-201,.

Yanagisawa O, Niitsu M, Yoshioka H, Goto K, Kudo H, Itai Y. (2003) The use of magnetic resonance imaging to evaluate the effects of cooling on skeletal muscle after strenuous exercise. *Eur J Appl Physiol* 89: 53-62.

Yeargin SW, Casa DJ, McClung JM, Knight C, Healey JC, Goss PJ, Harvard WR, Hipp GR. (2006) Body cooling between two bouts of exercise in the heat enhances subsequent performance. *J Stre Cond Res* 20(2), 383-389.

### STUDY III

#### A REVIEW OF CRYOTHERAPY EFFECTS ON EXERCISE AND SPORT PERFORMANCE

##### **ABSTRACT**

The application of cold therapy (e.g. ice, gel packs, cold water) is widely used to help manage injuries. Cryotherapy is also used as an exercise and sports ergogenic aid. Many studies show a positive effect of cryotherapy when it is applied under activity-specific protocols. However, cryotherapy can have detrimental effects if utilized for an extended period, such as swelling and decreased exercise and sport performance. This review discusses the effect of cryotherapy modalities on exercise and sport performance. In general pre-cooling core and extremity temperature provides a significant performance enhancement during endurance activities as well as high-intensity repeated exercise in the heat. The mechanisms responsible for the ergogenic effect of cryotherapy on high-intensity exercise remain unclear. Future research should examine the relationship of core and muscle temperature and skill performance of athletes in simulated or field conditions. Although preliminary results are positive, future research is required to determine the proper duration and ergogenic effects of applied cryotherapy during sports-specific activities.

**Key Words:** Ice, thermoregulation, cycling, baseball, running

## INTRODUCTION

Due to the positive effects of limb and tissue cooling on injury and performance, much interest has been generated as to whether cooling can be used as a preventative treatment or perhaps as an ergogenic aid. While there have been many studies, the findings are generally equivocal.

Cryotherapy pre-, post-, and during exercise or sport is a popular treatment (Marino, 2002). Cold therapy is widely accepted as a form of recovery from overuse injuries, muscular trauma and swelling, and muscular soreness. Cryotherapy is commonly used to reduce tissue temperature, metabolism, circulation of inflammatory markers and symptoms of delayed onset muscle soreness (DOMS) (Snyder et al., 2011; Cheung et al. 2003; Goodall et al., 2008; Howatson et al., 2008; Reilly et al., 2005; Marino 2002).

Humans maintain their body temperature within a narrow range over the entire course of their lives (Blight et al., 1985). Increases in physical activity have a concomitant increase in metabolic heat as a by-product. Humans are generally successful at maintaining the narrow range of core temperature in warm environments through various heat-loss mechanisms used to dissipate excess heat. However, tremendous stress is placed on the ability for the human body to stabilize core temperature when exposed to a hot and humid environment. This is due to a decrease in the evaporative heat loss that humans rely upon during physical activity in this circumstance (Gonzalez et al., 1988). This impaired ability to dissipate heat can lead to heat illnesses and symptoms of heat exhaustion and heat stroke; well recognized as potential risks of exercising in hot environments (Gardner et al., 1996). Extremes of both hypothermia and

hyperthermia can impair muscle function. It is evident that there must be an optimal temperature range for the best possible muscle performance (Crowley 1991).

Cryotherapy modalities have been utilized to attenuate in the rate of heat storage and increase the heat loss rate. However, there is a critical temperature for cold application, with inflammation and edema actually increasing at temperatures below 15 °C. Motor performance is affected by lowering temperatures approaching 18 °C, beneath which muscle performance decreases. These decreases are potentially explained by the neural component involved in muscle contraction (Barnes et al., 1985). Due to the potential harmful effects of cryotherapy, precautions should be taken to prevent prolonged or inappropriate applications.

Specific physical activity, such as the overhand throwing motion, places tremendous stress upon the upper extremity (Park et al., 2003, Atwater et al., 1979; Fleisig et al., 1995; Altchek et al., 1995; Paley et al., 2000; McCue et al., 1985; Burkhart et al., 2000; Litchfield et al., 1993) and is shown to increase the risk for overuse injuries. Szymanski (2009) reported the potential injuries related to baseball-specific activity. In particular, the large forces and torques essential to the overhand throw substantially stresses the shoulder during throwing. Fleisig and colleagues (1995) reported peak torque placed on the throwing elbow reaches the maximum capacity of the ulnar connective tissue. These stresses lead to micro-trauma in the soft tissues surrounding the shoulder and, due to the repetitive nature of baseball throwing, can result in overuse injuries from the accumulation of this damage.

To maximize repeat performance, as in the case with the overhand throwing athlete, a balance must be found between maintaining optimal joint mobility and attenuating injury risk. Studies have been performed of multiple techniques to minimize damage and improve recovery including the use of ice bags, cold gel packs as well as water immersion. Currently, no reviews

have systematically evaluated the literature regarding the effect of cryotherapy on sports performance. Therefore, the purpose of this review is to summarize and critically appraise the literature concerning the rationale and methodology of the effects of cryotherapy on exercise and athletic performance.

## **METHODS**

The investigators in the present study conducted a SportDiscus and PubMed search using the key words ‘cryotherapy’, ‘exercise’, and ‘sport performance’ between the years 1965 to present. The results of the search were examined for relevance. All studies evaluating cooling on physiology variables without performance outcomes were removed. The review was thus limited to 69 articles, with articles grouped by their respective modalities and activity-specific applications.

### *Cryotherapy Rationale*

It well established that exercise performed in the heat is prematurely terminated when compared to exercise in a temperate environment (Marino, 2002). Dugas and colleagues (2010) reviewed the effect of heat on performance, reporting reduced performance in the sports-specific activities of cycling and running. The review by Dugas explored the subjective mechanism behind athletes’ tendencies to slow down well before reaching a critical temperature. Physiological and subjective measures were taken at the point athletes began to slow down, where results were similar regardless of the environment of the performance (cool or hot environment). It was hypothesized that the body acts in a defensive manner when faced with unfavorable conditions, and a subconscious decision is made to reduce intensity before core

temperature reaches a critical value (Dugas et al., 2005). Daanan et al. (2005) support this hypothesis in a study where researchers documented the effect of prolonged heavy exercise in the heat. In this and similar research, a high core temperature was considered to be the factor limiting performance (Hasagawa et al., 2008; Galloway et al., 1997; Fortney and Vromen 1985; Terrados and Maughan 1995).

## **CRYOTHERAPY METHODS**

Marino (2002) reviewed the efficacy of pre-cooling as well as several cryotherapy strategies thought to improve performance and recovery during exercise under heat stress. There are multiple modalities of cryotherapy examined in the literature, with various situations and application times. Treatment modalities most commonly reported were cold-water immersion (Skuydas et al., 2006; Crowley 1991; Bailey et al., 2007; Goodall et al., 2008; Halson et al. 2008; Yeargin et al., 2006), ice-bag application (Dykstra et al., 2009; Richendollar et al., 2006; Tomchuk et al., 2010; Ihsan et al., 2010) and cold gel pack application (Kennet et al., 2007). Applications of cryotherapy can be delineated as whole body cooling (Pendergast et al., 1988), local-muscle cooling (Burgess et al. 2010) and vest cooling (Duffield et al. 2003, Hunter et al. 2006, Tegeder et al. 2008).

Potential negative reactions to cryotherapy have been reported, with cold therapy actually reducing the maximal force output contribution of active muscle fibers (Davies et al., 1982; Davies and Young, 1983; Faulkner et al., 1990; Petrofsky and Lind, 1981; Rome, 1990). Skin, subcutaneous, and intramuscular temperature changes depend on application methods and temperature, and intramuscular temperature will continue to drop after the cooling modality has

been removed (Meeusen et al., 1986). The equivocal findings in cryotherapy research are potentially due to the multiple application protocols utilized.

To properly utilize cryotherapy, careful consideration of effective modes of surface and tissue cooling must be assessed. Dykstra et al. (2009) tested multiple cold-therapy modalities, comparing the effectiveness of cubed, crushed and wetted ice on cooling the muscle and skin surface. Participants were given each of the treatments, with a four-day wash out period between trials. Skin and intramuscular temperatures were measured on the gastrocnemius every 30 s during a baseline, treatment, and recovery period. Dykstra reported differences among all treatments, with wetted ice producing the greatest overall temperature change during treatment and recovery. Investigators reported that among of the tested modalities, wetted-ice was superior to cubed or crushed ice at reducing surface and intramuscular temperatures. The rationale behind these findings could be due in large part to the ability of wetted-ice to maintain contact and cooling even before it melts, allowing for greater surface area contact compared to ice bags or water immersion.

## **CRYOTHERAPY AND PERFORMANCE**

Cryotherapy has been studied heavily, with its effects on exercise performance remaining poorly understood. Local cooling of various portions of the body including the legs, neck, arms and torso has significant effects on reducing muscle temperature. However, cooling of the extremities has resulted in equivocal findings with regard to the affect overall core temperature (Grahn et al., 2005; Long et al., 2005; Palmeiri et al., 2006).

Bergh and Ekblom (1979) performed a study testing the effects of whole body cooling using air on a combined leg and arm exercise protocol. The investigators discovered a

significant improvement in time to exhaustion during maximal work rate with cooling treatment when compared to the control. Results of this study supported the use of pre-cooling resulting in muscle temperature reduction. However, due to the complicated nature of whole body cooling utilizing cold-air, the approach has limited practical application.

Grahn et al. (2005) performed a study cooling of the palm of the hand during exercise. Grahn and colleagues combined application of sub-atmospheric pressure (35 – 45 mmHg) to an entire hand (to increase blood volume) and a heat sink (18 – 22°C) was applied to the palm surface to draw heat out of the circulating blood. Participants walked uphill on a treadmill in a hot environment (40 °C). Heat extraction through the palm attenuated the rate of core temperature increase during exercise ( $2.9 \pm 0.5$  °C vs.  $2.1 \pm 0.4$  °C) and increased exercise duration from  $32.3 \pm 1.7$  to  $46.1 \pm 3.4$  min, without and with the device, respectively). Researchers concluded that heat can be efficiently removed from the body by using the modality, providing a substantial performance benefit in hot environments.

Results of these studies suggest that whole-body cooling using cold-air reduces work-time during arm and leg isolation exercises, while significantly decreasing tissue temperature. Cooling of the palm is also seen to attenuate core temperature increases when walking uphill on a treadmill in a hot environment.

## *RUNNING*

Multiple studies have examined cryotherapy effects on running (Hunter et al., 2004; Arngrimsson et al., 2004; Tegeder et al., 2008; Price et al., 2009). In a study by Hunter et al. (2004), female cross-country performance was evaluated using an ice-vest as a pre-cooling method. Results of the study found that wearing an ice vest before cross-country performance

resulted in a lower core temperature post-race when compared to individuals who did not wear the vest. This study was limited in that the intervention was not tested on all subjects, in that it was a between group design. Tegeder et al. (2008) found similar results when evaluating ice vest effects on long-distance interval training in male runners, noting that a total of one hour of vest cooling; applied 30-minutes prior to and during the 30-minute warm-up, resulted in a significantly lower core temperature during long-distance interval running.

Arngrimmson et al. (2004) examined the effects of vest pre-cooling of the torso on 5-km performance, reporting that vest cooling significantly blunted increases of core temperature, heart rate and perceived thermal discomfort when compared to the control. Overall, Arngrimmson reported significantly lower 5-km time (13 s) in the vest cooling group, with an increased pace most evident in the last two-thirds of the run. These results suggested that the improved performance may be attributed to a reduced cardiovascular strain and subjective perception of heat early in the race, allowing for an improved performance later in competition.

Tyler et al. (2011) also looked at the effects of cooling on running performance at 70%  $VO_{2max}$  to volitional exhaustion. In their study, neck cooling increased time to volitional exhaustion by 13.5%, with neck cooling participants reporting subjective improvements over the control group while tolerating a higher end core temperature.

Price et al. (2009) examined the effects of no-cooling or ice-vest cooling as well as mid-cooling during intermittent running in the heat. Participants performed two 45-min periods of intermittent running separated by 15 min seated rest. This protocol was repeated on three separate occasions. Mean skin temperature and heat storage were calculated, with core temperature change from rest was greater during control when compared to both cryotherapy groups. Mean skin temperature was lower after both cryotherapy treatments and during the 15

min rest period and the first. Heat storage was also lower after pre-cooling modalities when compared to the control. The results of this study suggest that both cooling strategies were effective in reducing heat strain during intermittent exercise in the heat. It was found that pre-cooling combined with mid-cooling (cooling during the competition) was superior to pre-cooling alone (Price et al., 2009).

Results of these studies show that pre-cooling the torso significantly blunted core temperature increases for male and female cross-country runners. Researchers also report that torso cooling using a vest prior to running 5km can improve performance by reducing time to completion. Though pre-cooling has been shown to improve running performance, pre-cooling combined with mid-cooling was found to be superior concerning the reduction of heat strain during intermittent sprint performance.

## *CYCLING*

Many studies have been published examining cycling performance and the potential ergogenic effects of cryotherapy (Gabrys et al., 1993; Marsh and Sleivert 1999; Booth et al., 2001; De Pauw et al., 2011; Ross et al. 2010). Gabrys et al. (1993) looked at the effect of neck cooling on core temperature increases and circulatory responses. Participants performed a graded exercise test (GXT) on a cycle ergometer at two separate intensities (50W; 100W). Subjects were randomly placed into three groups: normothermia, hyperthermia, and hyperthermia with neck cooling. The water temperatures used during neck cooling were 14.8 °C and 18.4 degrees °C, respectively. Neck cooling did not affect core temperature, but was associated with improvements in “circulatory efficiency” as evidenced by increased work capacity and reduced cardiovascular strain.

Marsh and Sleivert (1999) studied the effects of pre-cooling on 70-s cycling power performance in the heat (29 °C, 80% relative humidity). In this study cryotherapy significantly decreased core and skin temperature. After pre-cooling, heart rate was also significantly lower than in the control condition (no cooling) throughout the warm-up. Ratings of perceived exertion were significantly lower ( $p < 0.05$ ) than in the control condition by the end of the warm up. The investigators reported that 30 minutes of pre-cooling improved the mean power output by 2.7% during intermittent 70-s cycling performance. The investigators suggested that the increase in available blood to the working muscle due to skin vasoconstriction from cold-water immersion explained performance improvements.

In 2001, a simulated cycling performance after pre-cooling was evaluated in hot conditions (Booth et al. 2001). When averaged over the 35-minute cycling period, muscle and esophageal temperatures after pre-cooling were reduced by 1.5 °C and 0.6 °C respectively, compared with the no-cooling control. Pre-cooling had a limited effect on muscle metabolism, with no differences between the two conditions in metabolites such as lactate, glycogen, triglyceride or adenosine triphosphate at rest or post-exercise. These data indicated that the benefit of pre-cooling may be that the athlete is able to draw on reserves later in the performance rather than just being able to maintain a given intensity or speed. The basis for this assumption is likely the previously reported tendency for participants to reduce intensity during exercise in the heat prior to reaching critical core temperature.

De Pauw et al. (2011) presented a study in which the effects of different recovery strategies including cryotherapy were evaluated in repeated time trial cycling performances. Investigators compared passive rest with and without upper leg cooling (0 °C or 10 °C), active recovery with and without upper leg cooling (temperature set to 0 °C), and compression after

initial time trial performance. In this study, no significant changes were seen in time trial performance for the recovery interventions, though there was a decline in skin temperatures during cooling interventions. It was noted by the authors that though performance was not significantly different between the trials, active recovery did result in a tendency towards slightly better subsequent time trials. However, it should be noted that this was a between-groups design, which could have affected results.

Ross et al. (2010) tested a novel cooling protocol during a simulated cycling time-trial. Participants were randomly placed into three groups: control (CON), cold-water immersion (CWI) and a combination ice slurry/iced towel modality (NC). The control group consisted of cold-water ingestion ad libitum, the CWI group consisted of cold-water immersion of the whole body and the NC group combined iced towels with drinking an ice-slush (14g per kg body weight) made from a sports recovery drink. Both cryotherapy techniques (CWI, NC) had an observable effect on core temperature before the time trial began. The NC group was associated with a 3.0% increase in power and a 1.3% improvement in performance time compared to control. The investigators concluded that this alternative cooling strategy was a practical and effective technique that combined external and internal cooling methods before performing a cycling time trial in a hot and humid environment.

Cooling has been successfully utilized as an ergogenic aid with cycling. Application of cryotherapy on the neck during a cycling GXT has been shown to reduce cardiovascular strain as well as increase overall work capacity. Pre-cooling has also resulted in an increase in power and decreases in cardiovascular strain and core temperature during intermittent cycling performance. Recovery beverage ice slurry/iced towel combinations can also be used as an ergogenic aid during cycling time trial performance, though the recovery beverage could attribute benefits due

to macronutrient content. While it is well documented that extended pre-cooling can attenuate increases in core temperature, the effects of cryotherapy on metabolism during exercise are unclear.

## **CRYOTHERAPY IN SPORTS**

Multiple studies examined absolute work and endurance exercise of pre-cooled subjects in a temperate environment (Hessemer et al. 1984, Grahn et al. 2005). Hessemer et al. (1984) investigated the effects of lowering core temperature in male rowers while exercising. Multiple endurance variables were recorded including total work, session duration, oxygen uptake and sweat rate. Results indicated that the average work rate was 6.8% greater in the pre-cooled treatment when compared to the control, with oxygen uptake 9.6% higher than seen during the control. Sweat rate was 20.3% lower in the pre-cooled treatment. Researchers concluded that pre-cooled rowing athletes were able to perform more work, maintain a higher  $\text{VO}_2$  and reduce the rate of sweating in a temperate environment when compared to athletes who were not pre-cooled.

Clarke et al. (2011) evaluated the use of carbohydrates and pre-cooling and the potential ergogenic effect on intermittent exercise. The participants performed 90 min of soccer-specific high-intensity exercise on four separate occasions. During two of the four sessions, participants were given pre-cooling treatments while consuming either a carbohydrate-electrolyte solution or a placebo. During the other two sessions subjects were given either a carbohydrate solution or a placebo. At 15 min intervals, participants were given a concentration test and performed a high-intensity exercise capacity test following each trial. High-intensity exercise duration was improved ( $79.7 \pm 7\text{s}$  vs  $70.1 \pm 8\text{s}$ ;  $p < 0.05$ ) with carbohydrate ingestion and cooling combined.

These results demonstrated pre-cooling as well as pre-cooling combined with carbohydrate ingestion helped maintain exercise capacity as well as mental performance during intermittent exercise in the heat.

In a study on baseball performance, baseball pitching was evaluated with heating and cooling interventions (Hannan et al.1999). Subjects performed simulated pitching trials using the treatments ice, heat and control for five innings. Either pre-cooling (crushed ice packs), heating (hydroculator pack) and control took place for 20 min following a generalized warm-up and immediately before the first inning. The simulated baseball game consisted of 75 total pitches, with 15 pitches thrown each inning. Accuracy and velocity were recorded for each pitch, with accuracy evaluated by whether or not a pitch went through a pre-rendered grid zone. It was found that administering pre-heat or pre-cooling modalities prior to activity did not alter accuracy or velocity for non-elite pitchers.

Verducci (2001) examined three-minute intermittent cryotherapy application during pitching performance. Participants threw 22 pitches at a rate of one pitch every 15 seconds. A one-minute pause was taken between each batter before continuing the trial, and eight-minutes were taken between innings to apply treatments. Pitchers gave a subjective fatigue rating at the end of each inning, with a rating of 3 leading signifying sufficient arm fatigue and the end of the trial. Verducci stated that the intermittent cryotherapy application significantly delayed the onset of fatigue by increasing the total pitches thrown by 26%. Mean velocity in the cryotherapy group was also increased for all of the pitches recorded, while no differences were seen in accuracy. Verducci also noted that icing subjectively reduced arm soreness after a 24-hour period, although the mechanisms involved remained obscure.

Results of cryotherapy research indicate that that pre-cooled rowing athletes perform greater work, have higher  $VO_2$  and reduce sweat rate in a temperate environment when compared to athletes who were not pre-cooled. Study results have also demonstrated pre-cooling and pre-cooling/carbohydrate ingestion combined helped maintain soccer-specific exercise capacity as well as mental concentration during intermittent exercise in the heat. Pre-cooling does not appear to affect baseball pitching velocity or accuracy, though intermittent cooling between innings appears to attenuate decreases in velocity and increase total work capacity in pitching.

## **CRYOTHERAPY AND RECOVERY**

Utsunomiya et al. (2010) found that cooling previously fatigued muscles lengthened the duration of subsequent exercise. During sustained isometric muscle actions, fatigue occurs and manifests as a reduction in force. The 10-min cooling intervention employed by Utsunomiya and colleagues extended isometric muscular endurance when compared to the control condition ( $59.2 \pm 11.5$ ,  $73.1 \pm 18.4$  and  $80.7 \pm 12.4$ , respectively). Study results suggest that 10-min cooling for fatigued muscles would improve recovery and extend the duration of subsequent isometric exercise.

The effects of cryotherapy on soreness and recovery post-exercise have also been studied, though the mechanisms are not well understood (Burgess et al., 2010, Skuvydas et al., 2006). Burgess et al. (2010) reported the potential positive effects of cryotherapy on the symptoms of delayed onset muscle soreness (DOMS). Burgess reported that cryotherapy decreased anti-inflammatory and catabolic markers in the blood, as well as improved subjective perceptions of DOMS symptoms. Halson et al. (2008) reported subjective enhancements of recovery of all

participants after cold-water immersion following cycling in the heat ( $34.3 \pm 1.1$  °C). All subjects completed both a cold-water immersion trial ( $11.5^{\circ}\text{C}$  for 60 s repeated three times) and a control (passive recovery in  $24.2 \pm 1.8^{\circ}\text{C}$ ). Heart rate, core and skin temperatures were all significantly lower in the cold-water immersion treatment. Results suggested a significant reduction in heart rate and core temperature after cold-water immersion.

Other studies reported similar findings to that of Halson and colleagues (2008). Vaile et al. (2010) reported cycling performance was sustained (+0.1%) after a cold-water immersion treatment (15 min at  $0.3$  °C) was maintained compared with the active recovery treatment, which saw performance decrease ( $-1.81\%$ ). These results indicate cold-water immersion was an effective intervention for recovery during repeated cycling performance.

These results indicate cold-water immersion significantly reduced heart rate, core temperature and was an effective intervention for recovery during repeated cycling performance. Research results suggest that 10-min cooling of fatigued muscles improved recovery and duration of subsequent isometric exercise.

## **NEUROMUSCULAR PERFORMANCE AND CRYOTHERAPY**

There is a critical lower temperature for cold application, with inflammation and edema increasing at temperatures below  $15$  °C (Meeuson et al., 1986). Temperatures at or below  $18$  °C begin to affect motor performance. These rates of diminishing muscle temperature are possibly explained by the effect of temperature on the neural component involved in muscle contraction (Barnes et al., 1985). Barnes et al. (1985) investigated the effects heat and cold interventions on maximum isometric grip strength. This study enlisted two groups of participants: one group dedicated to heating and the other to cooling. Cooling improved maximum grip strength  $8.29\%$

immediately following the application of cold. The group exposed to heating experienced a 17.93% decline in grip strength during treatment. Barnes suggested that temperature influences both the neural and mechanical components of muscular contractions, though limitations are present due to the between-group design.

Cryotherapy has been briefly evaluated during weight training. In a study done by Verducci, (2001), intermittent cryotherapy was examined during weight training. Subjects pulled 75% of their respective 1-repetition maximum on two different days. A treatment of cooling (ice) or towels were placed over the arms and shoulders of the participant, while they rested at room temperature for 4.5 minutes. Verducci reported that cryotherapy application of 3 min between weight pulling sets increased velocity and power for the first to fourth sets, with all-sets comparisons reported to have 14.5% more pulls with intermittent cooling. In this study, 3 min of intermittent cooling had no adverse effects on neuromuscular control or performance.

Study results suggest temperature influences both neural and mechanical components of muscle contraction. However, 3-min of intermittent cooling of the shoulder and forearm had no adverse effects on neuromuscular control or performance.

## **CRYOTHERAPY AND BIOCHEMISTRY**

Cooling of the muscle has also been reported to affect muscular biochemistry and blood metabolite dynamics. Booth et al., (2001) found that a reduced muscle temperature coincided with a reduction in metabolic cost of activity, promoting greater muscular endurance during 35 min cycling trials. Comparisons of pre-cooling treatments were made between 52 min of whole-body immersion into cold water (29 °C to 24 °C) and 45 min of thermoneutral water (34.8 °C).

Beelen et al. (1991) tested the effectiveness of immersing cyclists' legs in cold water (12 °C) after a long bout of endurance exercise (>42 min). In this study, peak lactate values were reached after approximately 9 minutes, with no significant difference between treatments at the end of the exercise bout. During the cooling trial, significantly higher peak values of blood lactate were found when compared to the control, indicating potentially faster lactate removal during exercise after cooling.

Burgess and Lambert (2010) reviewed the effects of cryotherapy on recovery. They reported that the literature revealed cryotherapy decreased anti-inflammatory and catabolic markers in the blood, as well as improved the subjective perception of DOMS symptoms with the pain-relieving properties of cryotherapy.

Cryotherapy can reduce inflammatory markers in the blood, as well as potentially increase peak lactate values during cycling. This effect of cooling on muscular biochemistry indicates a potentially faster lactate removal during exercise. Studies report a decrease in catabolic markers in the blood. Due to the pain-relieving properties of cryotherapy, study results suggest improved perceived effects of DOMS with the pain-relieving properties of cryotherapy.

## **EFFECT ON JOINT STABILITY AND ROM**

Currently researched cryotherapy protocols appear safe and to have limited effect on proprioception. Trembley et al. (2001) published a study suggesting that the force required for weight distribution was not significantly affected by cooling the quadriceps. To determine their respective differential threshold, subjects performed a weight discrimination task. Investigators concluded that the force signals required to distribute weight did not appear to be affected by the local cooling of the upper leg.

Cordova and colleagues (2010) performed a study investigating a combination of ankle bracing with local cooling of the joint. Local cooling of the ankle and ankle bracing are often used in together to treat an ankle injury. Twenty-four participants performed a sudden inversion perturbation to the ankle under each treatment. Cordova reported that combining ankle braces and local cryotherapy of the ankle did not have a harmful effect on dynamic stabilization of the ankle joint.

These findings conflict with Wassinger and colleagues (2007) who reported a reduction in proprioception and performance after ice pack application (20 min) to the shoulder. Participants demonstrated significant deviations when attempting to replicate a joint movement path after cold therapy. The authors stressed the importance of understanding deficits that occur after cryotherapy, as this modality is commonly used following acute injury and during rehabilitation.

Research results highlight the importance of understanding performance deficits that occur after cryotherapy. This modality is common following acute injury and during rehabilitation. Investigators concluded that cooling of the upper leg did not appear to affect weight distribution. Research suggests that combining cryotherapy and ankle braces does not significantly affect dynamic stabilization of the ankle joint. However, cryotherapy on some participants significantly affected fine motor movement when attempting to replicate a joint movement path.

## **CONCLUSION**

The current evidence suggests whole body pre-cooling is able to increase capacity for prolonged exercise at various ambient temperatures by allowing a greater capacity for heat

storage. Pre-cooling successfully attenuated the rate of core temperature increases, providing an advantage to those exercising in the heat (Gabrys et al., 1993; Marsh and Sleivert 1999; De Pauw et al., 2011; Ross et al., 2010; Booth et al., 2001, Hunter et al., 2004; Tegeder et al., 2008; Arngrimmson et al., 2004; Price et al., 2009). In most cases, subjects who used pre-cooling modalities generally maintained higher exercise intensities when compared to control treatments. These advantages were not associated with perceivable biochemical or cardiovascular advantages, leaving the mechanisms still undetermined.

With the current evidence, future research on pre-cooling should focus on practical studies, due to the difficulty in reproducing some of the tested protocols in competitive environments. Ice vests, gel packs and some cold-water immersions, are practical modalities for field use.

Understanding the proper uses of cryotherapy protocols is important when considering the potential benefits found in research. Study results have shown that proper utilization of cryotherapy is necessary in relation to proprioception, muscle temperature, and performance. Prolonged cryotherapy sessions at very low temperatures could have harmful effects. Overall, pre-cooling evidences positive effects on performance and as a viable therapy for rehabilitation. Cooling prior to exercise performance as well as during exercise combined appear to be most effective. When the activity provides the opportunity, intermittent or mid-competition cooling appears to have positive effects on heat strain, local muscle temperature, and subjective recovery.

Studies suggest athletes who utilize pre-cooling may be able to draw on reserves later in the performance rather than maintain a given intensity or speed (Hessemer et al., 1984, Grahn et al., 2005; Clarke et al., 2011; Hannan et al., 1999; Verducci et al., 2001, Yanagisawa et al., 2003).

Cryotherapy is widely used as a therapy to help manage injuries as well as an ergogenic aid. Proper application protocol for cryotherapy depends on a number of factors. Research suggests ice should be applied for 20 minutes, subtracting or adding time depending on the modality and activity-specific application. Pre-cooling core and extremity temperature provides a statistically significant performance enhancement during endurance activities as well as high-intensity repeated exercise in the heat requiring a mixture of aerobic and anaerobic energy supply.

The mechanisms responsible for the ergogenic effect of cryotherapy on high-intensity exercise remain to be determined. Future research should examine the relationship of core and muscular temperature, skill performance of athletes in simulated or field conditions. Although preliminary results are positive, future research is required to determine the ergogenic effects of applied cryotherapy research during sports-specific performance.

## REFERENCES

- Altchek DW, Dines DM: Shoulder injuries in the throwing athlete. (1995) *J Am Acad Ortho Surg* 3:159-165.
- Alvarez, GE, Kun Z, Kosiba, WA., Johnson, JM. (2006) Relative roles of local and reflex components in cutaneous vasoconstriction during skin cooling in humans. *Journal of Applied Physiology* 100 (6): 2083.
- Arngrimsson, Sigurbjorn A, Pettitt, Darby S., Stueck, Matthew G., Jorgensen, Dennis K., Cureton, Kirk J. (2004) Cooling vest worn during active warm-up improves 5-km run performance in the heat. *J Appl Physiol* 96: 1867–1874.
- Atwater AE. (1979) Biomechanics of overarm throwing movements and of throwing injuries. *Exerc Sport Sci Rev* 7:43- 85.
- Barnes, WS. Larson, MR. (1985) Effects of localized hyper- and hypothermia on maximal isometric grip strength. *American Journal of Physical Medicine* 64 (6): 305-314.
- Bergh U, Ekblom B. (1979) Physical performance and peak aerobic power at different body temperatures. *J Appl Physiol* 46:885–9.
- Bender AL; Kramer EE, Brucker JB, Demchak TJ, Cordova ML, Stone MB. (2005) Local Ice-Bag Application and Triceps Surae Muscle Temperature During Treadmill Walking. *Journal of Athletic Training* 40(4):271–275.
- Beelen, A. Sargeant, A.J. (1991) Effect of lowered muscle temperature on the physiological response to exercise in men. *Eur J Appl Phys Occ Phys* 63(5): 387-392.
- Bligh J. Regulation of body temperature in man and other mammals. In: Shitzer A, Eberhart RC, editors. Heat transfer in medicine and biology. New York (NY): Plenum Publishing 15-5, 1985.
- Bogerd N, Perret C, Boderd CP, Rossi RM, Daanen HA. (2010) The effect of pre-cooling intensity on cooling efficiency and exercise performance. *Journal of Sports Science* 28(7): 771–779.
- Booth J, Wilsmore BR, Macdonald AD, Zeyl A, Mcghee S, Calvert D, Marino FE, Storlien LH, Taylor NAS. (2001) Whole-body pre-cooling does not alter human muscle metabolism during sub-maximal exercise in the heat. *Eur J Appl Physiol* 84: 587-590.
- Burkhart SS, Morgan CD, Kibler WB. (2000) Shoulder injuries in overhead athletes: The “dead arm” revisited. *Clin in Sports Med* 19:125-158.

- Castle, PC, Macdonald, Adam L, Philip, A, Webborn, A, Watt, P and Maxwell, NS (2006) Precooling leg muscle improves intermittent sprint exercise performance in hot, humid conditions. *J Appl Physiol* 100: 1377–1384.
- Clarke ND, Maclaren DPM, Reilly T, Drust B. (2011) Carbohydrate ingestion and pre-cooling improves exercise capacity following soccer-specific intermittent exercise performed in the heat. *Eur J Appl Physiol* 111:1447–1455.
- Cordova, ML, Bernard LW, Au KK, Demchak, TJ, Stone MB, Sefton JM. (2010) Cryotherapy and ankle bracing effects on peroneus longus response during sudden inversion. *Journal of Electromyography and Kinesiology*. 20 (2): 348-353.
- Cornwell MW. (1994) Effect of Temperature on Muscle Force and Rate of Muscle Force Production in Men and Women. *Journal of Orthopaedic and Sports Physical Therapy* 20(2): 74-80.
- Cotter JD, Sleivert GG, Roberts WS, Febbraio MA. (2001) Effect of pre-cooling with and without thigh cooling, on strain and endurance exercise performance in the heat. *Comp. Biochem. Physiol. A. Mol. Integr. Physiol.* 128:667–677.
- Crowley GC, Garg A, Lohn MS, Someren NV, Wade AJ. (1991) Effects of cooling the legs on performance in a standard Wingate anaerobic power test. *Br J Sp Med* 25(4); 200-203.
- De Pauw, K, De Geus, B, Roelands, B, Lauwens, F, Verschueren, J, Heyman, E, Meeusen, Romain R. (2011) Effect of Five Different Recovery Methods on Repeated Cycle Performance. *Medicine & Science in Sports & Exercise* 43(5): 890-897.
- Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. (1995) Kinetics of baseball pitching with implications about injury mechanisms. *Am J Sports Med* 23(2):233-239.
- Fortney SM, Vroman NB. (1985) Exercise, performance and temperature control: Temperature regulation during exercise and implication for sports performance and training. 2(1): 8-20.
- Galloway, S.D.R. Shirreffs, S.M. Leiper, J.B. Maughan, R.J. (1997) Exercise in the heat: factors limiting exercise capacity and methods for improving heat tolerance. *Sports Exercise & Injury* 3(1): 19-24.
- Gabrys, J, Pieniasek, W, Olejnik, I, Pogorzelska, T, Karpe, J. (1993) Effects of local cooling of neck on circulatory responses in men subjected to physical exercise in hyperthermia. *Biology of Sport* 10 (3): 167-171.
- Gardner JW, Kark JA, Karnei K. (1996) Risk Factors Predicting Exertional Heat Illness in Male Marine Corps Recruits. *Med Sci Sports Exerc* 28: 939-44.

Grahn DA, Cao VH, Heller C, Dennis A. (2005) Heat extraction through the palm of one hand improves aerobic exercise endurance in a hot environment. *J Appl Physiol* 99: 972–978.

Gonzalez RR. (1988) Biophysics of heat transfer and clothing considerations. In: Pandolf KB, Sawka MN, Gonzalez RR (eds). Human performance physiology and environmental medicine in terrestrial extremes. Indianapolis (IA): Benchmark Press. pp 45-95

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

Gregson, W., Black, M., Jones, H., Milson, J., Morton, J., Dawson, B., Atkinson, G., Green, Daniel J. (2011) Influence of Cold Water Immersion on Limb and Cutaneous Blood Flow at Rest. *American Journal of Sports Medicine* 39 (6): 1316.

Hannan RL, Margarucci KD, Merkovsky SM, Knight KL, Ingersoll CD, Edwards JE. (1997) Effects Of Cooling And Heating The Shoulder On Pitching Velocity And Accuracy. *Journal of Athletic Training*: 32(2).

Halson SL, Quod MJ, Martin DT, Gardner AS, Ebert TR, Laursen PB. (2008) Physiological Responses to Cold Water Immersion Following Cycling in the Heat *International Journal of Sports Physiology and Performance* 3: 331-346.

Halvorson GA. (1990) Therapeutic heat and cold for athletic injuries. *Physician Sportsmed.* 18(5):87–92, 94.

Hessemer V, Langusch D, Brück K. (1984) Effect of Slightly Lowered Body Temperatures on Endurance Performance in Humans. *J Appl Physiol* 57: 1731–1737.

Hunter L, Hopkins TJ, Casa DJ. (2006) Warming up With an Ice Vest: Core body Temperature Before and After Cross-Country Racing. *J Athl Train* 41:371-374.

Howatson G, van Someren KA. (2008) The Prevention and Treatment of Exercise-Induced Muscle Damage. *Sports Med* 38(6): 483-503.

Ihsan M, Landers G, Brearley M, Peeling P. (2010) Beneficial Effects of Ice Ingestion as a Pre-cooling Strategy on 40-km Cycling Time-Trial Performance. *Inter J Sports Phys Perf* 5: 140-151.

Long BC, Cordova ML, Brucker JB, Demchak TJ; Stone MB. (2005) Exercise and Quadriceps Muscle Cooling Time. *J Athl Train* 40(4): 260–263.

Litchfield R, Hawkins R, Dillman CJ. (1993) Rehabilitation of the overhead athlete. *J Ortho Sports Phys Ther* 18:433-441.

- Kinugasa, R., Yoshida, K., Watanabe, T, Kuchiki, K, Horii, A. (2005) Skin Cooling alters the activation patterns of different heads of the quadriceps. *Can. J. Appl. Physiol.* 30(2): 127-139.
- Marino FE. (2002) Methods, advantages, and limitations of body cooling for exercise performance. *Br J Sports Med* 36: 89–94.
- Marsh D, Sleivert G. (1999) Effect of pre-cooling on high intensity cycling performance. *Br J Sports Med* 33:393–7.
- Meeusen, R, Lievens, P. (1986) The use of cryotherapy in sports injuries. *Sports Medicine* 3(6): 398-414.
- McCue FC, Gieck JH, West JO: Throwing injuries to the shoulder. In: Zarins B, Andrews JR, Carson WG (eds): *Injuries to the Throwing Arm*. Philadelphia: W.B. Saunders Co. 95-111, 1985.
- Nosaka K, Sakamoto K, Newton M, Sacco P. (2004) Influence of Pre-Exercise Muscle Temperature on Responses to Eccentric Exercise *Journal of Athletic Training* 39(2):132–137.
- Olsen, SJ, Fleisig GS, Shouchen D, Loftice J, Andrews JR. (2006) Risk Factors for Shoudler and Elbow Injuries in Adolescent Baseball Pitchers. *The American Journal of Sports Medicine* 34(6):905.
- Paley KJ, Jobe FW, Pink MM. (2000) Arthroscopic findings in the overhand throwing athlete: Evidence for posterior internal impingement of the rotator cuff. *Arthroscopy* 16:35-40.
- Palmieri RM, Garrison JC, Leonard JL, Edwards JE, Weltman A, Ingersoll CD. (2006) Peripheral Ankle Cooling and Core Body Temperature. *Journal of Athletic Training* 41(2):185–188.
- Petrofsky JS, Burse RL, Lind AR. (1981) The Effect of Deep Muscle Temperature on the Cardiovascular Man to Static Effort. *Eur J of Appl Phys and Occupational Physiology* 47(1): 7-16.
- Piedrahita, H, Oksa, J, Rintamäki, H, Malm, C. (2009) Effect of local leg cooling on upper limb trajectories and muscle function and whole body dynamic balance. *European Journal of Applied Physiology* 105(3): 429 10.
- Pendergast, D.R. (1988) The effect of body cooling on oxygen transport during exercise. *Medicine & Science in Sports & Exercise* 20 (5): S171-S176.
- Price MJ, Boyd C, Goosey-Tolfrey VL. (2009) The physiological effects of pre-event and mid-event cooling during intermittent running in the heat in elite female soccer players. *Appl. Physiol. Nutr. Metab.* 34: 942–949.

Richendollar ML, Darby LA, Brown TM. (2006) Ice Bag Application, Active Warm-up and 3 measures of Maximal Functional Performance. *Journal of Athletic Training* 41(4): 364-370.

Ross, M L. R. Garvican, L A.Jeacocke, N A.Laursen, P B.Abbiss, C R.Martin, D T.Burke, L M. Novel Pre-cooling Strategy Enhances Time Trial Cycling in the Heat. *Med Science in Sports & Exercise* 43(1):123. 2011.

Skuvydas A, Sipaviciene S, Krutulyte, Gailiuniene A, Stasiulis A, Mamkus G, Stanislovaitis A. (2006) Cooling Leg Muscles Affects Dynamics of Indirect Indicators of Skeletal Muscle Damage. *Journal of Back and Musculoskeletal Rehabilitation*. 19: 141-151.

Snyder JG, Ambegaonkar JP, Winchester JB. (2011) Cryotherapy for Treatment of Delayed Onset Muscle Soreness. *International Journal of Athletic Therapy and Training*. 16(4): 28-32.

Szymanski, DJ. (2009) Physiology of Baseball Pitching Dictates Specific Exercise Intensity for Conditioning. *Strength and Cond J* 31(2).

Tegeder AR, Hunter I, Mack GW, Hager R. (2008) Long-Distance Interval Training Following Pre-Cooling With an Ice Vest. *International Journal of Sports Science & Coaching*: 3(2).269-278.

Terrados N, Maughan RJ. (1995) Exercise in the Heat: Strategies to Minimize the Adverse Effects on Performance. *Journal of Sports Sciences*. 13(1): S55-63.

Thorsson, O. Lilja, B. Ahlgren, L. Hemdal, B. Westlin, N. (1985) The effect of local cold application on intramuscular blood flow at rest and after running. *Medicine & Science in Sports & Exercise* 17 (6): 710-713.

Tomchuck D, Rubley MD, Holcomb WR, Guandagnoli M, Tarno JM. (2010) The Magnitude of Tissue Cooling During Cryotherapy with Varied Types of Compression. *J Athl Train* 45(3): 230–237.

Tremblay, F, Estephan, L..Legendre, M Sulpher, S.(2001) Influence of local cooling on proprioceptive acuity in the quadriceps muscle. *Journal of Athletic Training* 36(2): 119-123, 2001.

Tyler CJ, Wild P, Sunderland, C. (2010) Practical neck cooling and time-trial running performance in a hot environment. *Eur J Appl Physiol* 110:1063-1074.

Utsunomiya, M, Nitta, K, Sawagichi, H, Yoshikawa, A, Karasuno, H, Morozumi, K, Allison, GT, Fujiwara, T., Abe, K. (2010) Changes in Blood Flow, Temperature and Muscle Endurance in Association with Cryotherapy. *Journal of Physical Therapy Science* 22 (1):43.

Vaile J, O'Hagan C, Stefanovic B. (2010) Effect of cold water immersion on repeated cycling performance and limb blood flow. *Br J Sports Med*.

Verducci FM. (2001) Interval Cryotherapy and Fatigue in University Baseball Pitchers. *Res Quarterly for Exercise and Sport* 72(3): 280-287.

Verducci FM. (2000) Interval Cryotherapy Decreases Fatigue During Repeated Weight Training. *Journal of Athletic Train* 35(4): 422-426.

Wassinger CA, Myers JB, Gatti JM, Conley KM, Lephart SM. (2007) Proprioception and Throwing Accuracy in the Dominant Shoulder After Cryotherapy. *Journal of Athletic Training* 42(1):84-89.

Yanagisawa, O, Miyanga, Y, Shiraki, H, Himojo, H, Mukai, N, Niitsu, M, Itai, Y. (2003) The effects of various therapeutic measures on shoulder strength and muscle soreness after baseball pitching. *J Sports Med Phys Fitness* 43: 189-201.

Yanagisawa O, Niitsu M, Yoshioka H, Goto K, Kudo H, Itai Y. (2003) The use of magnetic resonance imaging to evaluate the effects of cooling on skeletal muscle after strenuous exercise. *Eur J Appl Physiol* 89: 53-62.

Yeargin SW, Casa DJ, McClung JM, Knight C, Healey JC, Goss PJ, Harvard WR, Hipp GR. (2006) Body cooling between two bouts of exercise in the heat enhances subsequent performance. *J Strength and Cond Research* 20(2): 383-389.

## OVERALL CONCLUSION

Study results have shown the appropriate cryotherapy methodology is necessary in relation to proprioception, muscle temperature, and performance. Overall, cold therapy evidences positive effects on performance and as a viable therapy for rehabilitation. Pre-cooling combined with exercise performance as well as during exercise combined appears to be most effective. When appropriate, repeated or mid-competition cooling has been used with positive effects on heat strain, local muscle temperature, and subjective recovery.

The current evidence suggests whole body pre-cooling is able to increase capacity for extended exercise at various temperatures by allowing a greater heat storage capacity. Research shows pre-cooling successfully attenuated the rate of core temperature increases, providing an advantage to those exercising in the heat (Gabrys et al., 1993; Marsh and Sleivert 1999; De Pauw et al., 2011; Ross et al., 2010; Booth et al., 2001, Hunter et al., 2004; Tegeder et al., 2008; Arngrimmonson et al., 2004; Price et al., 2009). In most cases, subjects using pre-cooling methods were able to maintain elevated exercise intensities when compared to control treatments. Study results show pre-cooling core and extremity temperature provides a statistically significant performance enhancement during endurance activities as well as high-intensity repeated exercise in the heat.

There have been multiple studies involving repeated cooling. In these studies, intermittent cooling lasting 4-min between innings of a simulated baseball game was shown to significantly blunt the increases in rectal temperature in baseball catchers and attenuate velocity decrease in baseball pitchers. Intermittent cooling of the shoulder and forearm as well as the torso provided a significant improvement in perceived recovery and subjective exertion during simulated baseball performances.

Future research should examine the relationship of core and muscular temperature, skill performance of athletes in simulated or field conditions. Although preliminary results are positive, future research is required to determine the ergogenic effects of applied cryotherapy research during sports-specific performance.

With the current evidence, future cryotherapy research should focus on practical studies, focusing on ice vests, gel packs and some cold-water immersions for practical field modalities. The mechanisms responsible for the ergogenic effect of cryotherapy on high-intensity intermittent activity are still unclear. This practical treatment and the potential positive effects could improve pitching performance and might reduce overuse injuries.

## APPENDICES

**The Effect of Local Muscle Cooling on Baseball Performance**

**INFORMED CONSENT FORM**

**UNIVERSITY OF ALABAMA**

**Individual's Consent to be in a Research Study**

You are being asked to participate in a research project titled, "The effect of local muscle cooling on baseball performance". The study is being done by Stacy Bishop. He is a PhD candidate in the Kinesiology department in the College of Education. You will complete 5 total sessions including 4 throwing sessions separated by 5 days of recovery. During recovery, you will be asked not to do any heavy weight training (2-8 repetitions reaching muscle failure) during and between your sessions. You will also be asked not to exert maximum effort throwing for 24-hours after each session for the entire study. Minimal throwing effort (light warm-up throwing) will be permitted after the 24-hours. Endurance training (distance running, Stairmaster, elliptical runner etc.) will be permitted. If you agree to participate, you will be testing a new method to treat pitchers in between innings. maximum

**What is this study about?**

As of now, there are many methods for keeping a pitchers arm warm in between innings. Current methods may not be the best way to improve performance or prevent injury. Our study is testing the effect of cooling the shoulder and forearm in pitchers and vest cooling on catchers in between innings and the effect the cooling has on performance.

**Why is this study important?—What good will the results do?**

This study is important because it potentially helps a throwing athlete on many levels. Cold treatments are shown to reduce swelling, inflammation, and seen to improve performance. The information we learn during this study can help determine if more tests need to be done to potentially help prevent overuse injuries and increase a pitchers ability to throw harder for a longer period and help a catcher's performance in the heat.

**Participant Initials** \_\_\_\_\_

**Why have I been asked to take part in this study?**

You are being asked to participate in this study because you are a healthy male and a trained baseball player who throws 2 or more times per week for  $\geq 20$  minutes per session.

**How many other people will be in this study?**

The investigator hopes to include a minimum of 10 total people in this study involving baseball pitchers and catchers.

**What will I be asked to do in this study?**

If you agree to be in this study, as a pitcher you will be asked to perform 4 separate throwing sessions with 5 days between each session. As a pitcher in this study, you will be asked to maintain your normal routine for throwing with the exception of refraining from heavy weight lifting (2-8 repetitions reaching muscle failure) the day before each trial.

For catchers you will be asked to repeat your trial for 3 sequential days. As a catcher in this study, you will be asked to self-insert a flexible rectal thermometer approximately 10 centimeters into the rectum. As a catcher in this study, you will be asked to maintain your normal routine for throwing. However we do ask that you stay away from heavy weight lifting (2-8 repetitions reaching muscle failure) the 24-hours before each trial. You will be asked to perform 3 sessions in a row, each session separated by a 24-hour period. We will do this two (2) times, to simulate two (2) 3-game baseball series.

**How much time will I spend being in this study?**

The first session should last about 45-60 minutes. Each trial following will last 45-60 minutes.

**Will being in this study cost me anything?**

The only cost to you is your time.

**Will I gain for being in this study?**

In appreciation of your time, you will be informed about your pitch speed/accuracy during a simulated game. As a catcher, you will learn how the heat affects you mentally and physically.

**What are the risks (problems or dangers) from being this study?**

Our experiment presents some degree of risk; you will be closely supervised through all sessions. You will not be asked to do anything that goes beyond your level of training. The work you will be performing is similar to your normal amount of throwing.

Participants Initials \_\_\_\_\_

The test we are using simulates a normal baseball game and you will be able to eat your normal diet. A CPR and AED certified researcher will be present during testing, and a hospital with emergency personnel is less than a mile away. In the event of accident or injury, we will supply first aid and summon medical help as necessary.

If emergency medical treatment is needed, this will be at your expense. The U of A will not assume responsibility for the cost of further medical care.

**What are the benefits of being in this study?**

There is a low risk of injury due to your training level, and potentially no benefits of being in this study.

**How will my privacy and confidentiality be protected?**

There will be potential participants in the lab, so it is possible you will not be in a secluded area. The information collected during this study linked with your name will only be seen by the investigators. Your name will be replaced with an ID number. Your name will never be associated with this study in any way. All data will be coded after collection. Data will be maintained in a locked file cabinet in Dr. Bishop's office for a period of 2 years after completion of the research project. It is our intent that the data will be published.

**How will my confidentiality be protected?**

The only places your name appears in connection with this study are on this informed consent, the health status questionnaire and the PAR Q. These forms will be kept in a locked file drawer in Dr. Bishop's office, which is locked when he is not there.

**What are the alternatives to being in this study?**

The only alternative is not to participate.

**What are my rights as a participant?**

Being in this study is by your choice alone. If you start the study, you can stop at any time. Not participating or stopping participation will not affect your relationships with the University of Alabama.

The University of Alabama Institutional Review Board is a committee that looks out for the ethical treatment of people in research studies. They may review the study records if they wish. This is to be sure that people in research studies are being treated fairly and that the study is being carried out as planned.

Participant Initials \_\_\_\_\_

**Whom do I call if I have questions or problems?**

If you have any problems or questions, you can contact Stacy H. Bishop, 254 624 4912, or the faculty advisor Dr. Phillip Bishop, PO Box 870312, University of Alabama, Tuscaloosa, AL 35487-0312, 205-348-4699. If you have questions about your rights as a person taking part in a research study, make suggestions or file complaints and concerns, you may call Ms. Tanta Myles, the Research Compliance Officer of the University at (205)-348-8461 or toll-free at 1-877-820-3066. You may also ask questions, make suggestions, or file complaints and concerns through the IRB Outreach Website at [http://osp.ua.edu/site/PRCO\\_Welcome.html](http://osp.ua.edu/site/PRCO_Welcome.html). You may email us at [participantoutreach@bama.ua.edu](mailto:participantoutreach@bama.ua.edu).

**Consent:**

I have read the above and freely and voluntarily agree to participate in the above-described research study. I agree to be a participant in this exercise study and understand that there are no penalties for declining to participate and that I can withdraw at any time without penalty.

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Signature of Research Participant \_\_\_\_\_ Date \_\_\_\_\_

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Signature of Investigator \_\_\_\_\_ Date \_\_\_\_\_

**Contact Information:**

Name \_\_\_\_\_ Phone \_\_\_\_\_

Address \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**Please initial and date in the space provided below if you agree to continue participation in this study:**

Session I \_\_\_\_\_ (initials) \_\_\_\_/\_\_\_\_/\_\_\_\_

Session II \_\_\_\_\_ (initials) \_\_\_\_/\_\_\_\_/\_\_\_\_

Session III \_\_\_\_\_ (initials) \_\_\_\_/\_\_\_\_/\_\_\_\_

Session IV \_\_\_\_\_ (initials) \_\_\_\_/\_\_\_\_/\_\_\_\_