Spring 2020

The Effect Of Intermittent Cooling On Simulated Basketball Game Performance

Dalton E. Cousin

THE EFFECT OF INTERMITTENT COOLING ON SIMULATED BASKETBALL GAME PERFORMANCE

by

DALTON COUSIN

(Under the Direction of Greg Ryan)

ABSTRACT

Context: Hyperthermia is induced during prolonged exercise which promotes fatigue and a decline in performance. Basketball athletes have trouble preventing an onset of hyperthermia; thus, cryotherapy is applied intermittently to combat the negative effects. **Objective:** To determine, (1) effect intermittent cooling has on simulated basketball performance, perceived exertion and perceived recovery; and (2) change in performance while applying two different forms of intermittent cooling during the Basketball Specific Fatigue Protocol (BSFP). **Design:** Crossover study design. **Setting:** Indoor collegiate basketball court. **Patients or Other Participants:** Sixteen competitively trained recreational basketball athletes (15 males, 1 female; age = 21.1 ± 1.2 yr). **Main Outcome Measures:** Participants completed 3 trials of the BSFP. Between quarters, intermittent cooling was applied for 5-minutes to the lower extremity using either a phase changing material (PCM), wetted ice (WI) or received no treatment (control). Change in countermovement jump height (ΔCMJ), 10m sprint time (ΔST), heart rate (ΔHR), ratings of perceived exertion (RPE) and perceived recovery score (PRS) were recorded each quarter. **Results:** PRS found to significantly increase starting quarter 2 (Q_2), (7.0 ± 2.0, p = 0.02), with significantly higher PRS at Q_2 using the PCM (7.5 ± 2.0, $p < 0.01$). HR and ST saw significant change between quarters (ΔHR: Q_1 = 81.8 ± 2.6 bpm, $p < 0.01$; ΔST: Q_1 to Q_4 (- 0.2 ± 0.1 s, $p = 0.02$), Q_2 to Q_4 (- 0.1 ± 0.0 s, $p = 0.03$), but not between conditions (ΔHR: $p = 0.51$, ΔST: $p = 0.33$). RPE significantly increased each quarter until the completion of the simulated game ($p < 0.01$). **Conclusions:** Intermittent cooling, applied to the lower extremity via PCM, can increase perceived recovery through the first half of simulated basketball game performance.

INDEX WORDS: Cryotherapy, Hyperthermia, Athletic performance, Recovery

THE EFFECT OF INTERMITTENT COOLING ON SIMULATED BASKETBALL GAME PERFORMANCE

by

DALTON COUSIN

B.S., Alfred University, 2018

M.S., Georgia Southern University

A Thesis Submitted to the Graduate Faculty of Georgia Southern University in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

WATERS COLLEGE OF HEALTH PROFESSIONS

THE EFFECT OF INTERMITTENT COOLING ON SIMULATED BASKETBALL GAME PERFORMANCE

by

DALTON COUSIN

Major Professor: Greg Ryan

Committee: John Dobson

Samuel Wilson

Electronic Version Approved:

May 2020

TABLE OF CONTENTS

ACKNOWLEDGMENTS

The authors would like to thank the Georgia Southern University Graduate Student Organization and the Jack N. Averitt College of Graduate Studies for sponsoring this study by funding all material costs through the Graduate Student Professional Development Fund. GlacierTek would also like to be acknowledged for providing the custom lower extremity phase changing material wraps for this study. We would also like to thank; James Spencer, William Bean, Skylar Lance, Joseph Benitez and Ryan Lawless for their assistance with data collection.

LIST OF FIGURES

Page

CHAPTER 1

INTRODUCTION

During prolonged exercise, the human body increases temperature in working skeletal muscle and cutaneous tissue as a byproduct of metabolic heat production, termed hyperthermia.[1,2,3,4,5,6] Once exercise begins, hyperthermia causes blood to revert from the skeletal muscle to the cutaneous tissue as an act to cool the body to homeostasis.[4,5,6,7] Reduction in blood flow to working skeletal muscle produces a decrease in buffering capacity and oxygen delivery to the working tissue.[1,3]

Athletes have difficulty decreasing internal temperature produced by the working extremities once the onset of hyperthermia occurs.[1,3] In turn, the athlete experiences a reduction the total amount of oxygen delivered to the working tissue.[4,5,6,7] A decrease in available oxygen produces an increase in fatigue and a decrease in performance by the athlete.[5] Fatigue is defined as a decrease in a performance variable accompanied with an increase in perceived effort to achieve performance.[8] Thus, cryotherapy can be applied as an attempt to attenuate the onset of hyperthermia.

Cryotherapy provides various applications in sports medicine including; reduction of swelling, bleeding, inflammation, pain, and rehabilitation.[9] When a wetted ice (WI) bag (0.5℃) is applied to a localized area for 10 minutes, cutaneous tissue temperature decreases significantly by 14.2℃ and shows minimal effect on skeletal muscle (0.8℃).[2] After 10 minutes, skeletal muscle begins to decrease at a greater rate, which should be noted for safe prescription.[2] Alternative forms of cryotherapy, such as a phase changing material (PCM) wrap, are used to produce the same effect as WI. However, the PCM maintains a higher temperature at 15℃ and remains flexible for easy application.[10] As cutaneous tissue begins to cool, blood perfusion is increased within skeletal muscle, allowing fatigue to be delayed.[4] The result is an increase in oxygen transport and utilization, which continues until the tissue rewarms (~15 min post application).[11]

Reduction of heat is not likely feasible during competition because the athlete cannot loosen or remove clothing. Due to this problem, external cryotherapy has previously been used to mitigate hyperthermia by decreasing cutaneous temperature.[1,3,12] Cryotherapy via ice vest has shown to decrease ratings of perceived exertion (RPE) during treadmill exercise while increasing participant completion rates.[3] However, ice vests have only shown to have a significant vasoconstricting effect following a bout of exercise, but not during.[12] Additional to temperature change, the ice vests have not shown significant improvement during performance.[12]

Although ice vests lack evidence to improve performance, alternative forms of cryotherapy have shown to exhibit beneficial effects when prescribed intermittently. Cold water immersion (CWI) and active recovery were previously compared between two cycling bouts. When compared to active recovery, CWI showed to significantly decrease cutaneous leg blood flow, arm blood flow and heart rate starting the second bout of exercise.[13] Intermittent cooling via CWI also shows to significantly decrease cycling and running race time.[13,14] Improvement in performance was attributed to a decrease in rectal temperature following the cooling periods, showing that intermittent cooling has application across a variety of sports.[13,14]

Intermittent cooling, in the form of CWI, has shown to improve performance but has minimal practical application during athletic competition. An alternative approach is applying intermittent cooling to a localized body region, commonly in the form of WI. WI was tested on collegiate basketball players and when applied to the anterior knee, found to increase maximal voluntary isometric contraction (MVIC) at the vastus lateralis post treatment.[15] The improvement in MVIC quantifiably displays how localized cryotherapy can affect strength.[16] Baseball pitchers have also applied localized WI to the posterior shoulder and medial elbow, intermittently between innings for 4 minutes. Over a 6-inning simulated game, intermittent cooling was found to prevent velocity loss, decrease RPE and improve perceived recovery.[17] Although similar performance benefits have been shown in both aerobic and anaerobic activity, sport specificity must be acknowledged when prescribing the location of application and duration of treatment.

Various sports have shown performance benefits while utilizing intermittent cooling, but basketball has limited investigation. Basketball requires multidirectional movements that recruit the lower extremity musculature, including; the countermovement jump (CMJ), 10m sprint and side shuffle. Identical in-game basketball fatigue has been defined within the basketball-specific fatigue protocol (BSFP).[18] The BSFP was created by using time motion analysis of a multiple basketball competitions to create a valid and reliable simulated game that induces the specific amount and type of fatigue.[18] As defined by the BSFP, athletes cover a total distance of 6,880.8m per competition at varying intensity intervals; low (1088.7 ± 57.3s), medium (639.2 ± 27.2s) and high (363.7 ± 5.0s). Additionally, 68 CMJs and 971 changes in direction are completed during competition.[18]

A reduction in basketball performance can be attributed to repeatedly performing each movement, which subsequently causes an onset of hyperthermia.[6] A reduction in performance and lower extremity fatigue has been seen within collegiate level basketball athletes. The study showed that athletes experienced an increase in rectal body temperature, 10m sprint time and a decrease in power output over the course of a simulated game.[19] However, CMJ height was not affected by the simulated basketball game due to the low intensity interval providing enough time for anaerobic recovery.[6,19]

The CMJ is a powerful movement in basketball that recruits the lower extremity musculature.[6] During the CMJ, the quadriceps provide height by concentrically contracting during the take-off phase, while the hamstrings are activated eccentrically during the landing phase.[20,21] Having a reduction in eccentric power output in the hamstrings can effect in-game performance and increase the athletes chance of injury.[22] The biomechanics of the CMJ also include action at the talocrural joint; having an agonist-antagonist relationship between the gastrocnemius and soleus.[23] Limiting lower extremity fatigue during competition should be a high concern for basketball athletes to maintain performance and reduce injury.

The purpose of this study was to determine the effect intermittent cooling, using WI or a phase changing material (PCM) wrap applied to the lower extremity, has on change in CMJ height (ΔCMJ), 10m sprint time (ΔST), heart rate (ΔHR), RPE and perceived recovery score (PRS) during a simulated basketball game. The second purpose is to determine if performance wearing the PCM is comparable to WI. Applying cryotherapy to the lower extremity intermittently, could provide an alternative approach to mitigate the negative hyperthermic effects associated with a high-intensity aerobic activity such as basketball.

CHAPTER 2

METHODS

THE EFFECT OF INTERMITTENT COOLING ON SIMULATED BASKETBALL GAME PERFORMANCE

Participants:

Research was conducted on 16 competitively trained recreational basketball athletes (*n* = 16; age = 21.1 ± 1.2yr; height = 178.8 ± 8.4cm; weight = 84.5 ± 11.1kg). All participants had prior experience playing competitive basketball defined as a minimum of varsity engagement during high school. Each participant performed aerobic exercise at least three times a week lasting for a minimum duration of one hour. Participants completed an informed consent, Physical Activity Readiness-Questionnaire Plus (PAR-Q+) and health questionnaire. All participants reported to be free of injury and cold related illness (e.g., cold urticaria, Raynaud's) for the last 6 months. All participants refrained from the consumption of sports performance supplements, caffeine and alcohol for at least 24 hours prior to the start of each trial. A short-sleeved shirt, basketball shorts, socks and basketball shoes were worn by the participants as well as spandex to avoid direct cryotherapy contact at the thigh.

Experimental Approach:

The BSFP is a simulated basketball game which induces in-game basketball fatigue with high reliability.[18] Participants are required to; travel a distance of 6,605.7m, complete 68 maximal CMJs and change direction 971 times.[18] To maintain practicality, a BSFP trial consists of 4 quarters separated by 5-minutes rest after quarters 1 and 3, and 15-minutes at half time. One quarter entails 17 consecutive rounds of high (3-5 m/s), medium (1.5-3 m/s) and low intensity (≤ 1.5 m/s) bouts of play. Overall time in each intensity is intervaled to create the specific game play fatigue (high: 17.0%, medium: 31.0% and low 52.0% of the time).[18] Rounds begin with a maximal effort CMJ leading into high intensity sprints and shuffles. Medium intensity follows beginning with backpedaling and leading into a shuffle. Low intensity completes each round, allowing participants to walk and recover.[18] See *Figure 1* for the depiction on direction and intensity of each movement. If a specific intensity interval was not completed within the desired time frame, for two consecutive rounds, then participants were asked to stop the trial and return 7 days later. A 10-minute dynamic warm up was completed on the testing court from baseline to baseline before beginning the protocol. No warmup was administered after scheduled rest periods between quarters.

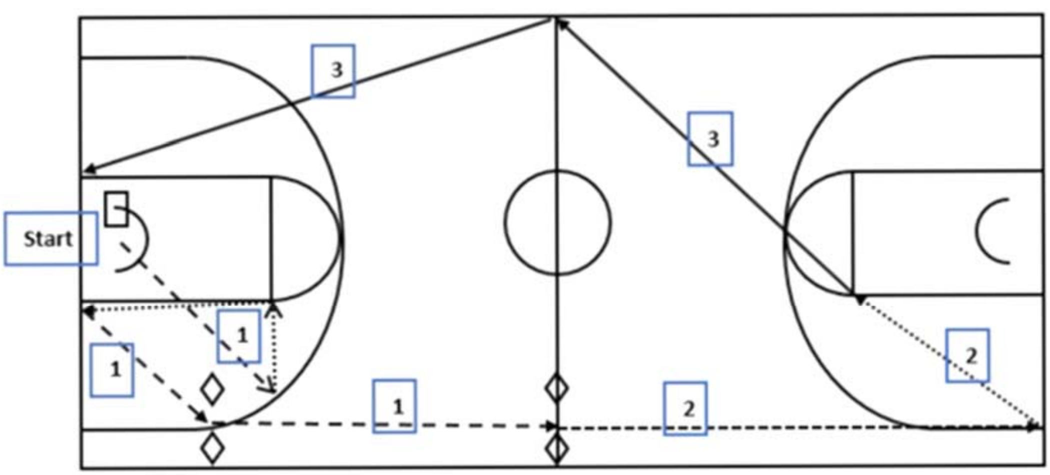

***Figure* 1.** Interval for one round of the basketball-specific fatigue protocol (BSFP).

Legend: ◇ timing gate, □ jump mat, — — ▶ sprint, ·········▶ shuffle, ------▶ backpedale, - - - ▶ walk; 1 = high intensity, 2 = medium intensity, 3 = low inensity

In randomized counterbalanced fashion, participants completed a familiarization session and 3 trials of the BSFP. All trials took place on an indoor basketball court with identical collegiate floor dimensions. One of three treatments (PCM, WI, C) were randomly selected and applied to the lower extremity during scheduled rest periods.

Performance was measured by recording CMJ height, 10m sprint time and HR during the 17 rounds in each quarter. CMJ height was assessed using the Just Jump mat (Probotics Inc., Huntsville, AL, USA), set on the court beneath the right side of the backboard (position referenced facing basket). 10m sprint time was collected using a Brower TC timing gate (TC, Brower Timing Systems, Draper, UT, USA). The first timing gate was set 3.0m in front of the baseline, on the left side of the court and positioned perpendicular across the 3-point line. A second timing gate was located 10m down court and positioned parallel over the half court line. *Figure 1* displays positioning of the jump mat and timing gates. A Polar HR monitor (Polar Electro Incorporated, Bethpage, NY, USA) was fitted with a chest strap to continuously record HR during simulated play.

Subjective measurements were evaluated and recorded to quantify perceived recovery and exertion using the 10-point PRS and 6-20 Borg RPE scale.[24,25] The 10-point PRS was assessed at the end of each rest interval to evaluate the subjective recovery between each quarter. The 10-point PRS is a 0-10 point scale representing the participants perceived recovery with 10 representing full recovery and 0 representing no recovery.[25] The Borg RPE 6-20 scale assessed perceived exertion at the completion of each quarter with 6 indicating no exertion and 20 indicating maximal exertion.[25] A visual analog scale with numerical marks was provided for both PRS and RPE.

Simulated Basketball Game Protocol:

After receiving approval from the Georgia Southern University Institutional Review Board, participants were recruited and instructed to the Georgia Southern University Human Performance Lab 24-48hrs before the first trial. The informed consent, PPAR-Q+ and health questionnaire were completed and reviewed at this time. Participants' height, weight, age and estimated max heart rate (HRmax) were collected. A familiarization session was then conducted resolving any questions pertaining to the PCM, WI, BSFP, PRS and RPE scale.

Trials began with participants fitting tubular sleeving over the calf to avoid direct cryotherapy skin contact and fitting the Polar HR monitor to the chest. Participants completed the dynamic warmup and an opportunity for water was provided. Quarter 1 began with participants reporting current PRS and HR. CMJ height and 10m sprint was recorded within the 17 rounds of every quarter with HR recorded at the completion of each round. RPE was recorded following all 17 rounds for each quarter. Participants completed rest seated in a chair located on the sideline of the court with instruction to drink water ad-libitum. Following the completion of each trial, participants were instructed to complete a self-selected cooldown stretch. Trials were separated by a minimum of 7 days' rest.

During seated rest, intermittent cooling was applied to the lower extremity for 5-minutes via PCM, WI, or received no treatment (C). An athletic training certified researcher applied the intermittent cooling treatment to all participants. Trial 1 fitted four PCM wraps (GlacierTek, Minneapolis, MN, USA) enveloping the quadriceps, hamstring and calf musculature bilaterally. Trial 2 incorporated WI. Six WI bags (Medco Sports Medicine, Amherst, NY, USA) were applied bilaterally and held by elastic wrapping to the; quadricep (anterior medial muscle belly), hamstring (posterior medial muscle belly), and calf (posterior muscle belly). Trial 3 received no treatment. Intermittent cooling was applied at half time from minute 5-10 with no application between minute 0-5 and 10-15. The PCM was unwrapped, re-cooled in an ice chest and sanitized, while WI was cut loose from the wrapping following each trial.

Data Analysis:

Data was analyzed using IBM SPSS Statistics 25 with an alpha value was set to 0.05. CMJ height and 10m sprint time were analyzed based on mean change between the first three rounds (1, 2, 3) and the last three rounds of each trial (15, 16, 17): $CMJ_1 + CMJ_2 + CMJ_3 \div 3 = CMJ_s$; $CMJ_{15} + CMJ_{16} + CMJ_{17} \div 3 = CMJ_f$; $\Delta Q = CMJ_s - CMJ_f = \Delta CMJ_1$). HR was analyzed based on the same ΔQ method but evaluated starting and ending HR each quarter. A 3 (PCM, WI, C) x 4 [Q_1, Q_2, Q_3, Q_4] repeated measures analysis of variance (ANOVA) was run on [ΔCMJ, ΔST, ΔHR]. A Bonferroni post hoc analysis was completed on all significant main effect findings. 3 (PCM, WI, C) x 4 [Q_1, Q_2, Q_3, Q_4] Friedman ANOVAs were run on [PRS, RPE]. All data is presented as mean ± standard deviation for continuous variables, and median ± interquartile range (IQR) for all categorical data. The effect-size for all significant post-hoc relationships were calculated using Cohen's *d*, and assessed using the following criteria: <0.2 = small; 0.2 to 0.79 = moderate; ≥ 0.8 = large.[26]

CHAPTER 3

RESULTS

Heart Rate:

Analysis utilized a Greenhouse-Geisser correction and found a significant ΔHR between each quarter, [$F(2.3, 45) = 49.1$, $p < 0.001$]. Post hoc analysis testing found a significance mean increase in ΔHR when comparing Q_1 to all other quarters ($Q_1 = 81.8 \pm 2.6$ bpm, $Q_2 = 63.8 \pm 1.8$ bpm, $Q_3 = 64.0 \pm 1.7$ bpm, $Q_4 = 60.3 \pm 1.8$ bpm, $p < 0.001$). No significance was found when comparing WI, PCM and C [$F(2, 45) = 0.7$, $p = 0.51$] (*figure* 2).

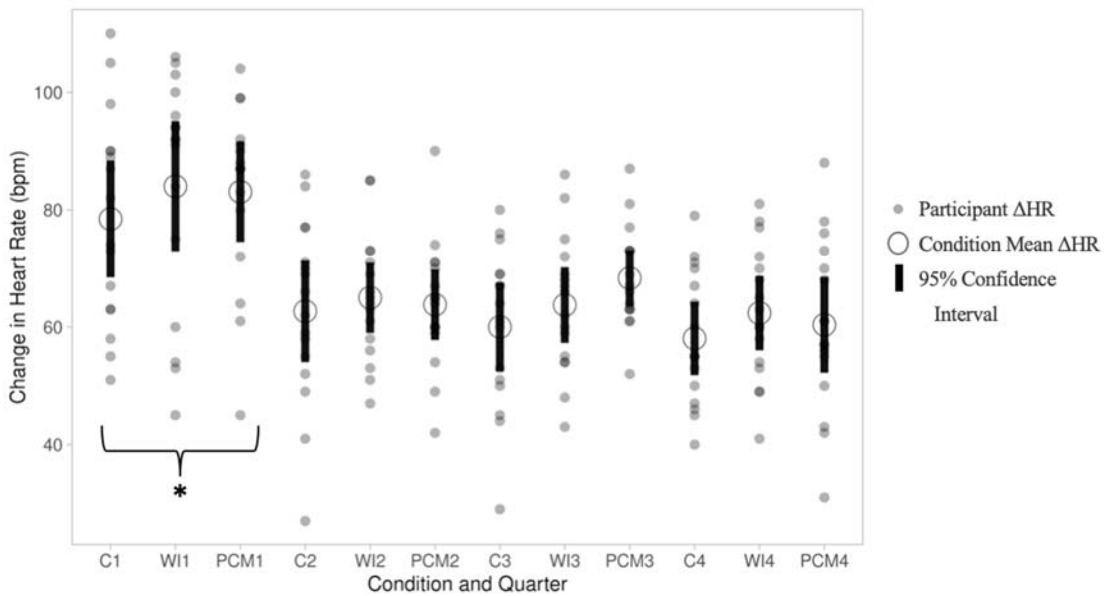

***Figure* 2.** Comparing change in heart rate (ΔHR) for the phase change material (PCM), wetted ice (WI), and control trials over 4-quarters. Statistical significance was found in quarter 1 (Q_1) showing an increased mean ΔHR compared to all other quarters (81.83 ± 2.61 bpm, $p < 0.01$). No difference was seen when comparing conditions over the 4-quarters of play ($p = 0.51$). Note: numbers attached to the x-axis labeled condition denote quarter (e.g., C1 = control Q_1). Asterisk indicates a statistically significant difference ($p < 0.05$).

10m Sprint Time:

ΔST was analyzed using a Greenhouse-Geisser correction, determining a significant difference between quarters [$F(1.6, 45) = 3.5$, $p = 0.05$]. Post hoc analysis found a mean decrease in ΔST from Q_1 to Q_4 (- 0.2 ± 0.1 s, $p = 0.02$) and Q_2 to Q_4 (- 0.1 ± 0.0 s, $p = 0.03$) (*figure* 3). No statistical significance was found between any condition [F(2, 45) = 1.1, $p = 0.33$)].

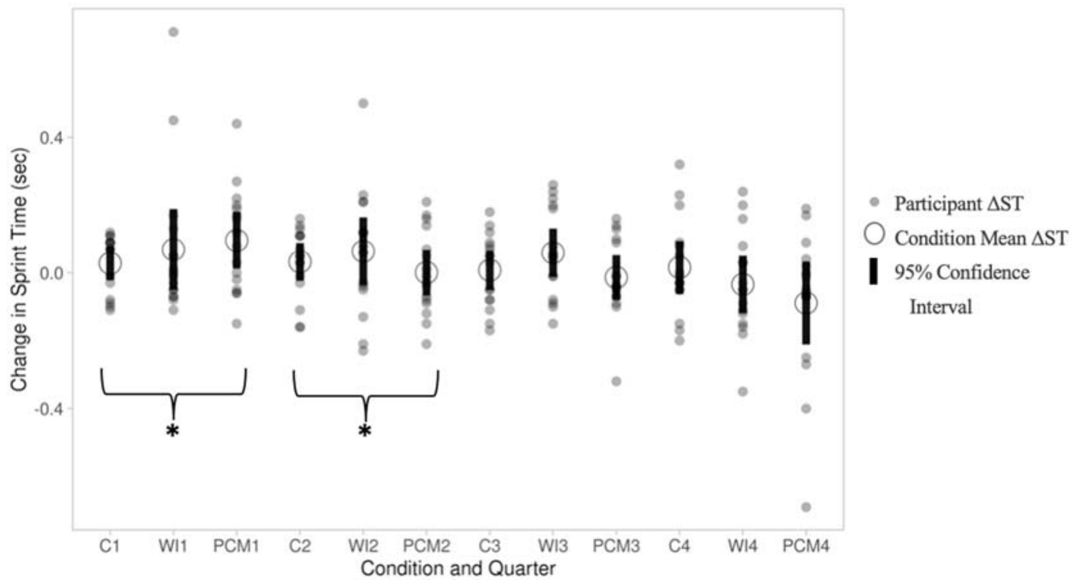

***Figure* 3.** Change in sprint time (ΔST) between the phase change material (PCM), wetted ice (WI), and control are compared. Mean ΔST significantly decreased from quarter 1 (Q_1) to quarter 4 (Q_4) (- 0.2 ± 0.1, $p = 0.02$) and quarter 2 (Q_2) to Q_4 (- 0.1 ± 0.0 s, $p = 0.03$). Significance was not found comparing conditions ($p = 0.33$). Note: numbers attached to the x-axis labeled condition denote quarter (e.g., WI2 = wetted ice Q_2). Asterisk indicates a statistically significant difference ($p < 0.05$).

Countermovement Jump Height:

Analysis of ΔCMJ height found no significance in mean change in height over 4-quarters of simulated play [F(1, 45) = 0.1, $p = 0.71$]. Pairwise comparison between conditions also showed insignificance [F(2, 45) = 0.9, $p = 0.43$].

Perceived Recovery Scale:

PRS was found to produce a statistically significant increase in median score beginning Q_2 when compared to all other quarters, $X^2(2) = 8.3$, $p = 0.02$; median IQR (7.0 ± 2.0 at Q_2, 7.0 ± 1.8 at Q_3 and 7.0 ± 2.0 at Q_4). Post hoc analysis showed the PCM to have a significant, moderate increase in PRS at the start of Q_2 when compared to WI ($p < 0.001$, $d = 0.25$) and C ($p < 0.001$, $d = 0.63$); median IQR (PCM: 7.5 ± 2.0, WI: 7.0 ± 1.0 and C: 6.0 ± 2.8) (*figure* 4).

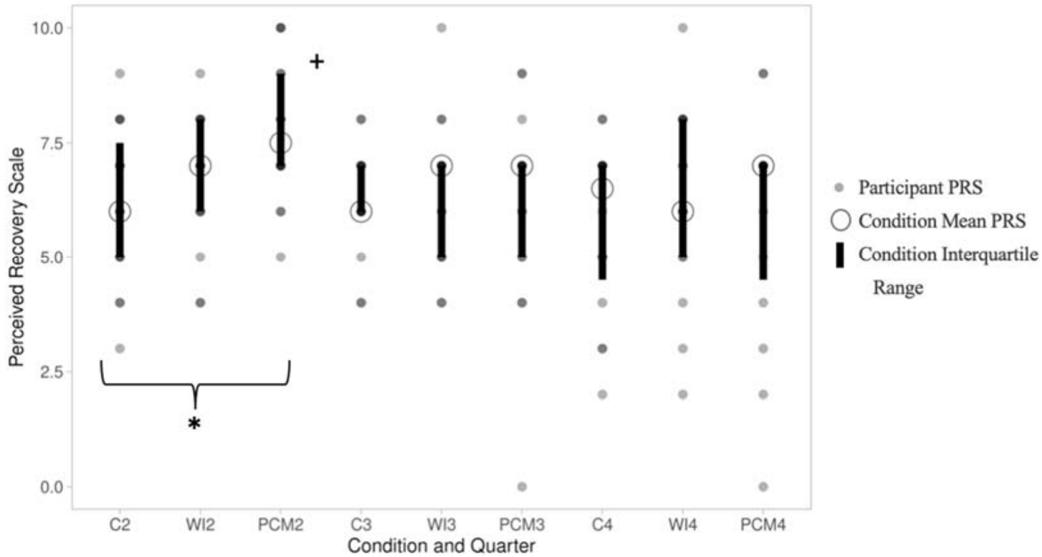

***Figure* 4.** Intermittent cooling on perceived recovery scale (PRS) during the simulated game. Median PRS was significantly greater at the start of quarter 2 (Q_2) when compared to all other quarters; median interquartile range (IQR) = 7.0 ± 2.0, $p = 0.02$. The phase changing material (PCM) showed a significantly higher PRS at Q_2 than all other conditions (median IQR = 7.5 ± 2.0, $p < 0.01$). Note: numbers attached to the x-axis labeled condition denote quarter (e.g., PCM2 = phase changing material Q_2). Asterisk and plus sign indicate a statistically significant difference ($p < 0.05$).

Ratings of Perceived Exertion:

RPE showed a statistically significant median increase from the start of the simulated game to the end $X^2(3) = 56.1$, $p < 0.01$; median IQR (Q_1 = 10.5 ± 3.0, Q_2 = 12.0 ± 2.0, Q_3 = 12.0 ± 2.8, Q_4 = 13.0 ± 2.8). Post hoc analysis revealed no difference in RPE when comparing conditions over 4-quarters (*figure* 5).

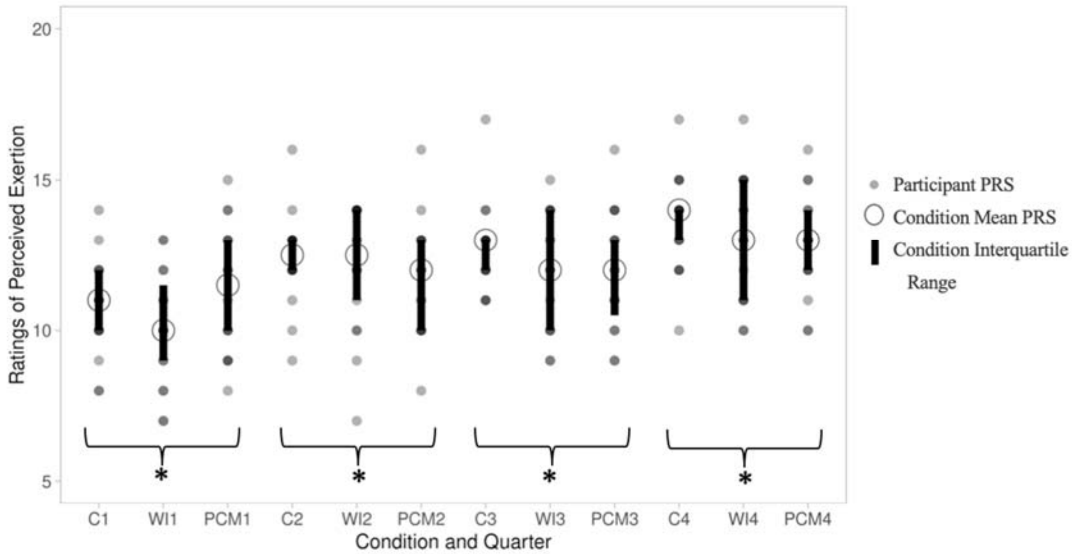

***Figure* 5.** Comparing the change in ratings of perceived exertion (RPE) during the simulated basketball game. Mean RPE significantly increased after quarter 1 (Q_1) and each quarter following until completing quarter 4 (Q_4); median interquartile range (IQR) values total: $Q_1 = 10.5 \pm 3.0$, quarter 2 (Q_2) $= 12.0 \pm 2.0$, quarter 3 (Q_3) $= 12.0 \pm 2.8$, $Q_4 = 13.0 \pm 2.8$, $p < 0.01$. No statistically significant differences were seen comparing conditions. Note: numbers attached to the x-axis labeled condition denote quarter (e.g., C3 = control Q_3). Asterisk indicates a statistically significant difference ($p < 0.05$).

CHAPTER 4

DISCUSSION:

In the present study, 5-minutes of intermittent cooling to the lower extremity was investigated on simulated basketball game performance. Findings indicate that participants entered Q_2 with greater perceived recovery ($p = 0.02$). Intermittent cooling via PCM showed the highest perceived recovery during Q_2, scoring close to full recovery (WI: $p < 0.001$, $d = 0.25$; C: $p < 0.001$, $d = 0.63$). However, it should be noted that while significantly different, the actual change was small, which may mean there is limited practical significance. These findings agree with previous literature, determining that intermittent cooling caused an increase in perceived recovery.[17] An improvement in PRS using the PCM rather than the WI could be attributed to the temperature of treatment. The PCM maintains a cool temperature of 15℃ while WI presents close to freezing at 0.5℃.[2,11] The lower temperature of WI causes a greater decrease in cutaneous tissue temperature when compared to the PCM.[11] In turn, cutaneous temperature was unable to rewarm at the start of each quarter, causing participant discomfort and subsequently a decrease in performance.[11] Fatigue occurs when the body is induced into hyperthermia.[5,6] Applying the PCM increased perceived recovery which may mitigate the onset of hyperthermia and loss in performance from the first half to the second.

HR compared between quarters presented significant change during the first quarter ($p < 0.001$). The application of intermittent cooling found no effect on ΔHR ($p = 0.51$). A low resting HR before starting Q_1 and a high exercise HR at the conclusion may explain this finding. HR could not recover back to resting in the subsequent quarters, causing less change. A previous study examining intermittent cooling on 35-minute cycling performance agreed with the findings, showing ΔHR to be higher during the initial exercise bout.[13] However, the investigation found that HR decreased following intermittent cooling.[13] This opposes our second finding that intermittent cooling did not affect ΔHR. Results can be credited to the 60 minutes of intermittent cooling rest time.[13] The BSFP incorporates specific lengths of time to replicate quarters and half time.[18] Length of rest and intermittent cooling application may need to increase to see a significant ΔHR, but would reduce practical application.

Comparisons made each quarter on RPE showed a continual increase in perceived exertion from the end of Q_1 through the end of Q_4 ($p < 0.01$), but no significance was found for perceived exertion while utilizing intermittent cooling. Literature investigating RPE during basketball play agreed with our results that RPE increased with duration and intensity.[27] Although our results follow this trend, previous research assessing intermittent cooling on cycling performance bouts found conflicting results. The study showed that 15-minutes of intermittent vest and neck cooling caused RPE to be significantly lower following the second bout of exercise.[28] Reduction in perceived exertion was attributed to the 15-minute intermittent cooling application time and the location at the torso and neck. This form of cryotherapy application could promote greater heat exchange due to the location the cooling was applied at.[5] The location of our intermittent cooling treatment and length of application could explain the difference in findings.

Analysis found mean ΔST to decrease significantly from Q_1 to Q_4 ($p = 0.02$) and Q_2 to Q_4 ($p = 0.03$). Our findings are not concurrent in literature and can be explained by the level of competition created by the protocol. A study investigating college level basketball players during a live 40-minute scrimmage showed a decreased ST between Q_1, Q_2 and Q_3 before increasing in Q_4.[6] When comparing protocols, the BSFP is validated to induce identical in-game fatigue by performing movements associated in a basketball competition that do not incorporate a physical basketball, while the comparative study used a live 40-minute scrimmage. Performance during a live game or scrimmage shows greater participant exertion when compared to a simulated protocol.[29] The difference in results could be linked to additional motivation created while playing against an opponent. There was no significant difference found when comparing the PCM, WI and C ($p = 0.33$). These findings are backed in previous research that used intermittent cooling on soccer athletes. The study applied intermittent cooling during a soccer game and found ST to be unaffected by intermittent cooling.[30] Results were attributed to participants using a pacing strategy which created the ability to perform maximally at the start and end of each trial, while coasting through the middle. Adopting the pacing strategy caused a reduction in motivation, allowing participants to perform harder at the beginning and end of each quarter regardless of intermittent cooling application.[29,30]

No relationship was found between quarters ($p = 0.71$) or conditions for ΔCMJ height ($p = 0.43$), showing the CMJ was unaffected by the simulated game or intermittent cooling. Our analysis agrees with literature showing how CMJ height is not affected by a basketball competition.[6,18] The CMJ is an anaerobic movement that requires short, powerful contractions.[19,20] The low intensity walk just prior to completing the CMJ may have provided enough time for anaerobic recovery.[17]

This study applied intermittent cooling during a simulated basketball game. Although the protocol induced specific basketball fatigue, performance was measured in a simulation environment rather than competitive. The pacing strategy may have been adopted by the participants, which presents as a limitation in this study. Duration of intermittent cooling was completed for 5-minutes and only elicited a moderate significant change in PRS using the PCM at Q_2. Previous literature has shown improvement in performance measures by applying intermittent cooling for a duration greater than 10-minutes.[12,13,14] To maintain sport practicality, the 5-minute rest interval was not increased, creating limitation. Studies finding significant performance benefits from intermittent cooling have been predominantly either anaerobic or aerobic.[12,13,14,16] Basketball, however, incorporates both forms of activity at various intervals which may have induced hyperthermia at a different rate.[5,17]

Application of the PCM intermittently, appears to cause a moderate increase in perceived recovery during the first half of a simulated basketball game. Findings are associated with a mitigation in fatigue by slowing the onset hyperthermia. The potential benefits are seen when applying a form of intermittent cooling that is cold (~15.0℃), such as a PCM, but not freezing like a WI bag (~0.5℃). The lower treatment temperature produced a slower rewarming rate causing participant discomfort and reduction in performance beginning each quarter. Even so, the potential benefit while intermittent cooling with the PCM was small, which could limit the practical application.

REFERENCES

1. Bogerd N, Perret C, Bogerd C, Rossi R, Daanen HM. The effect of pre-cooling intensity on cooling efficiency and exercise performance. *J Sports Sci*. 2010; 28 (7): 771-779.
2. Hunter EJ, Ostrowski J, Donahue M, Crowley C, Herzog V. Effect of salted ice bags on surface and intramuscular tissue cooling and rewarming rates. *J Sport Rehabil*. 2016; 25 (1): 70.
3. Kenny GP, Schissler AR, Stapleton J, Piamonte M, Binder K, Lynn A, Lan CQ, Hardcastle SG. Ice cooling vest on tolerance for exercise under uncompensable heat stress. *J Occup Environ Hyg*. 2011; 8 (8): 484-491.
4. Mawhinnwy C, Low DA, Jones H, Green DJ, Costell JT, Gregson W. Cold water mediates greater reductions in limb blood flow than whole body cryotherapy. *Med Sci Sports Exerc*. 2017; (6): 1252.
5. Nybo L. Hyperthermia and fatigue. *J Appl Physiol.* 2008; 104: 871–878.
6. Pliauga V, Kamandulis S, Dargevičiūtė G, Jaszczanin J, Klizienė I, Stanislovaitienė J, Stanislovaitis A. The effect of a simulated basketball game on players' sprint and jump performance, temperature and muscle damage. *J Hum Kinet*. 2015; 46 (1): 167-175.
7. Kenney WL, Johnson JM. Control of skin blood flow during exercise. *Med Sci Sports Exerc.* 1992; 24 (3), 303-312.
8. Enoka RM, Stuart DG. Neurobiology of muscle fatigue. *J Appl Physiol*. 1992; 72 (5), 1631-1648.
9. Galiuto L. The use of cryotherapy in acute sports injuries. *Ann Sports Med Res*. 2016; 3 (2), 1060.

10. Michael JM, Susan YK, Andrew F, Malachy PM. Accelerated recovery of muscle function in baseball pitchers using post-game phase change material cooling: 2371 Board #35. *Medicine & Science in Sports & Exercise*. 2019; (6): 648. doi:10.1249/01.mss.0000562433.92269.39.

11. Kwiecien SY, McHugh MP, Goodall S, Hicks KM, Hunter AM, Howatson G. Exploring the efficacy of a safe cryotherapy alternative: physiological temperature changes from cold-water immersion versus prolonged cooling of phase-change material. *Int J Sports Physiol Perform*. 2019; 14 (9), 1288–1296.

12. House JR, Lunt HC, Taylor R, Milligan G, Lyons JA, House CM. The impact of a phase-change cooling vest on heat strain and the effect of different cooling pack melting temperatures. *Eur J Appl Physiol*. 2013; 113 (5), 1223-1231.

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

14. Yeargin SW, Casa DJ, McClung JM, Knight JC. Body cooling between two bouts of exercise in the heat enhances subsequent performance. *J Strength Cond Res*. 2006; 20 (2), 383.

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

16. Visser J, Mans E, De Visser M, Van den Berg-Vos RM, Franssen H, De Jong JMBV, De Haan RJ. Comparison of maximal voluntary isometric contraction and hand-held

dynamometry in measuring muscle strength of patients with progressive lower motor neuron syndrome. *Neuromuscul Disord*. 2003; 13 (9), 744-750.

17. Bishop SH, Herron RL, Ryan GA, Katica CP, Bishop PA. The effect of intermittent arm and shoulder cooling on baseball pitching velocity. *J Strength Cond Res.* 2016; 30 (4), 1027-1032.
18. Hůlka K, Lehnert M, Bělka J. Reliability and validity of a basketball-specific fatigue protocol simulating match load. *Acta Gymnica.* 2017; 47 (2), 92-98.
19. Alemdaroğlu U. The relationship between muscle strength, anaerobic performance, agility, sprint ability and vertical jump performance in professional basketball players. *J Hum Kinet*. 2012; 31, 149.
20. Jakobsen MD, Sundstrup E, Randers MB, Kjær M, Andersen LL, Krustrup P, Aagaard P. The effect of strength training, recreational soccer and running exercise on stretch–shortening cycle muscle performance during countermovement jumping. *Hum Mov Sci.* 2012; 31 (4), 970-986.
21. Padulo J, Tiloca A, Powell D, Granatelli G, Bianco A, Paoli A. EMG amplitude of the biceps femoris during jumping compared to landing movements. *Springerplus*. 2013; 2 (1), 520.
22. Bourne MN, Opar DA, Williams MD, Shield AJ.. Eccentric knee flexor strength and risk of hamstring injuries in rugby union: A prospective study. *Am J Sports Med.* 2015; 43 (11), 2663.
23. Dal Bello F, Cabello EN, Rueda J, Muñoz EA. Vertical jump characteristics and lower limbs muscular contribution in chilean volleyball players during the countermovement jump (CMJ). *Proceedings of the 35th International Society of Biomechanics in Sport*

Conference. Edinburgh, England: Edinburgh University Press; 2017: 35 (1): 202. https://commons.nmu.edu/isbs/vol35/iss1/202.

24. Laurent CM, Green JM, Bishop PA, Sjökvist J, Schumacker RE, Richardson MT, Curtner-Smith M. A practical approach to monitoring recovery: development of a perceived recovery status scale. *J Strength Cond Res*. 2011; 25 (3), 620-628.
25. Borg E, Kaijser L. A comparison between three rating scales for perceived exertion and two different work tests. *Scand J Med Sci Sports*. 2006; 16 (1), 57-69.
26. Cohen J. *Statistical power analysis for the behavioral sciences*. 2nd ed. Hillsdale, NJ: 12 Lawrence Erlbaum Associates; 1988.
27. Lupo C, Tessitore A, Gasperi L, Gomez MAR. Session-RPE for quantifying the load of different youth basketball training sessions. *Biol Sport*. 2017; 34 (1), 11–17.
28. Yudai C, Sumire O, Hiroshi H. Wearing a cooling vest during half-time improves intermittent exercise in the heat. *Front Physiol*. 2019; 10, 711.
29. Moreira A, McGuigan MR, Arruda AF, Freitas CG, Aoki MS. Monitoring internal load parameters during simulated and official basketball matches. *J Strength Cond Res*. 2012; 26 (3), 861-866.
30. Parris K, Tyler CJ. Practical torso cooling during soccer-specific exercise in the heat. *J Athl Train*. 2018; 53 (11), 1089–1097.
31. Daneshmandi H, Choobineh AR, Rajaee FA. Validation of borg's RPE 6-20 scale in male industrial workers of shiraz city based on heart rate. *Jundishapur Sci Med J*. 2012; 11 (76), 1-10.

32. Nunan D, Donovan GAY, Jakovljevic DG, Hodges LD, Sandercock GR, Brodie DA. Validity and reliability of short-term heart-rate variability from the Polar S810. *Medicine & Science in Sports & Exercise*. 2009; 41 (1), 243-250.
33. Haugen TA, Tønnessen E, Svendsen IS, Seiler S. Sprint time differences between single- and dual-beam timing systems. *J Strength Cond Res.* 2014; 28 (8), 2376-2379.
34. Pueo B, Jimeney-Olmedo JM, Lipińska P, Buśko K, Penichet-Tomás A. Concurrent validity and reliability of proprietary and open-source jump mat systems for the assessment of vertical jumps in sport sciences. *Acta Bioeng Biomech.* 2018; 20 (3).

APPENDIX A

LITERATURE REVIEW ON INTERMITTENT COOLING

During prolonged exercise, the human body increases temperature due to metabolic heat production, termed hyperthermia. Research has shown that hyperthermia increases temperatures in the working skeletal muscle and cutaneous tissue.[1,2,3,4,5,6] Once exercise begins, hyperthermia causes blood to be reverted from the skeletal muscle to the cutaneous tissue in order to cool the body back to homeostasis.[5,7] Utilizing 10-male participants, Kenny et. al. 2011, performed experimental sessions in the hot (35 °C) and wet (65% relative humidity) environments for a 120-minute aerobic treadmill workout. It was seen that prolonged aerobic exercise, regardless of the environment, caused an onset of hyperthermia ($p<0.05$).

Once hyperthermia occurs, athletes have difficulty decreasing temperature produced by the working extremities.[3] A study focusing on 8-healthy male participants were pre-cooled using an ice vest or received no cooling. Exercise was completed on a cycle ergometer and a significant increase in body temperature was seen for the control group but not the precooling group ($p<0.05$).[1] When a lack of blood flow to working skeletal muscle occurs, a decrease in buffering capacity and reduction in the amount of oxygen delivered to the working tissue follows.[4, 5] A reduction in oxygen produces negative effects by causing an increase in fatigue and a decrease in performance of the athlete. Fatigue is defined as a decrease in a performance variable accompanied with an increase in perceived effort to achieve performan.[8] Thus, cryotherapy is used by providing various applications in sports medicine including; the reduction of swelling, inflammation, pain, muscle spasm, bleeding, as well as improving rehabilitation and post orthopedic surgery.[9]

Cryotherapy, when applied over a muscle, will cause a cooling of the cutaneous tissue and overtime can cause an affect on intramuscular tissue regardless of the type of ice application. A study performed on 24-healthy participants used wetted ice, salt cubed, and salt crushed ice. The protocol applied the various ice applications to the posterior gastrocnemius and observed cutaneous and intramuscular temperature change for 30-minutes of cooling and 45-minutes of re-warming. The research found that cutaneous tissue temperature was cooled at a faster rate than the intramuscular cooling, regardless of the form of ice (p<0.01).[2] During the initial 10-minutes the cutaneous tissue of the wetted ice group decreased 14.2℃ verses 0.8℃ in the intramuscular tissue (p<0.01). Cutaneous tissue was cooled at a significantly greater rate when using wetted ice versus salted ice crushed and cubed (p<0.01). Intermuscular cooling did not see a significant decrease in temperature until 20.53-minutes (p<0.01).[2] This time frame is noted because if the ice is applied for too long, then the cooling effect could travel intramuscularly causing muscular tightness. Thus, it is essential that treatment time is short when applying cryotherapy intermittently. As cutaneous tissue is cooled, blood is then reverted to the muscle allowing fatigue to be delayed.[4] Blood perfusion, that occurs in the cutaneous tissue, is then seen to remain constant for 15-minutes before rewarming the tissue only 3.5℃ (Khoshnevis, Craik, & Diller, 2015). Investigation needs to continue to determine the effects that localized intermittent cooling has on various performance variables.

Reduction of heat is not likely feasible because the athlete cannot loosen or remove clothing during a competition. Due to this problem, a study used external cryotherapy, commonly in the form of an ice vest, to decrease localized cutaneous temperature over the working extremities.[28,30] The ice vest caused ratings of perceived exertion (RPE) to be significantly lower from 10-120 minutes than the control (p<0.05). The use of the ice vest allowed 9 out of 10 participants to complete the 120-minute protocol when compared to only 4 total participants completing the protocol without the ice vest. When continuing investigation, ice vest application found conflicting results. The ice vest continued to be studied on 10-healthy male volunteers during a 45-minute step test and 45-minutes of recovery. During this time there was no significant vasoconstricting effect during exercise. The ice vest did however have a vasoconstriction effect on cutaneous blood flow during the recovery period. Additional to temperature change, the study found that the ice vest did not show an improvement in performance over the course of the test.[12]

Although ice vests have displayed inconsistent results, alternative forms of external intermittent cooling exhibit beneficial effects. Recent research instructed participants to complete two 35-minute cycling bouts separated by 60-minutes of recovery between each bout. During the 60-minutes of recovery, participants were instructed to either participate in active recovery or intermittent cooling via cold water immersion. Prior to the second bout of exercise, results showed a significant decline in leg blood flow, arm blood flow and heart rate (active recovery 90 ± 11bpm; cold water 78 ± 15bpm) using cold water immersion when compared to active recovery ($p<0.05$). A significant -1.8 ± 1.1% reduction in performance was also seen in the active recovery group with the intermittent cooling group increasing .10 ± 0.7% ($p<0.05$).[13]

Intermittent cooling when applied to distance runners showed an improvement in race times in distance runners when applied to the lower extremity.[14] 15-participants completed a 90-minute trail run, followed by a 30-minute break, into a 2-mile race. During the 30-minute break, 12-minutes of either mock treatment, cold water or ice water immersion of the lower extremity took place. Participants showed a significantly lower rectal temperature and heart rate for both the cold water and ice immersion post race ($p<0.05$). When cold water or ice water was used during rest, race performance improved 6% ($p<0.05$) showing the practicality for improving aerobic bouts.[14] The study has provided the knowledge that intermittent cooling, for only 12-minutes, to the lower extremity produces the same effects across various aerobic activities.

Whole body immersion used intermittently has previously been used to improve performance but is not applicable to most athletes during the competition.[13] Thus, intermittent cooling would need to be applied at a localized area. Pietrosimone et al. in 2009, researched further into localized cooling, rather than immersion and upper torso cooling via ice vest. Specifically, the anterior knee was used to assess maximal voluntary isometric contractions (MVIC) over a period of time. Research was conducted on 11 volunteers completing repeated trials of MVIC on a Biodex for a knee extension. Participants were cooled via a wetted ice bag over the anterior knee for 20-minutes. Following 20-minutes, participants completed MVIC at 70° of knee flexion at 0, 20, 30, and 45 minutes. Results found that 20-minute of localized cooling over the anterior knee increased electromyography (EMG) output when compared to the control at both 20- (+10.69mv; -16.45mv, $p=0.03$) and 45-minutes' (+2.76mv; -24.08mv, $p<0.01$) post ice application over the vastus lateralis (VL). The control group was noted to have an overall decrease in EMG output over the 45-minute period. However, the rectus femoris (RF) did not see significant benefits ($p=0.57$). Because the RF flexes the hip as well as extends the knee, more information would need to be gathered at the hip to understand overall performance affect. Improvement at the VL shows us that ice applied to quadriceps musculature can increase MVIC. Improving MVIC can show the improvement or reduction in strength with quantifiable data.[16]

Athletes, such as baseball pitchers, have shown to prevent velocity loss, decrease ratings of perceived exertion, and improve recovery when applying cryotherapy between innings.[17] 8-

trained injury-free baseball pitchers were tested during a simulated baseball game. The game consisted of 12 pitches each inning followed with either no treatment or 4-minute ice bag application to the shoulder and forearm for 5 innings. Participants not only saw a significant 35% reduction in RPE scores (p=0.01), but also saw a significant reduction in velocity loss during the 4^{th} and 5^{th} innings (p=0.04).[17] The research described how proper application and duration of intermittent cooling is sport specific. Because of this, it was necessary in this study to apply ice to the elbow and shoulder musculature due to the recruitment during a pitch.

Various sports have shown the benefits in performance while using intermittent cooling, but basketball is absent in the investigation. Basketball is an aerobic activity requiring athletes to cover a 6,880.80m. Over the course of the competition, basketball athletes are required to compete at varying intensities including; low (1088.68 57.32s or 52.03% of the time), medium (639.21 27.17s or 31.66% of time) and high intensities (363.74 4.95s or 17.03% of time) while performing 68 CMJs and 971 changes in direction. During this time the body begins to experience fatigue causing a reduction in basketball performance.[18]

Pliauga et. al. 2015, showed how necessary lower extremity power output was in college level basketball players. Over the course of a warm-up and simulated basketball game athletes were tested on rectal body temperature, 10-m sprint time, and countermovement jump (CMJ) height. During the simulated game, each player experienced lower extremity fatigue causing a decrease in power output. Results showed a significant increase in both 10-m sprint times ($p<0.05$) and an increase in rectal body temperature ($p<0.05$) causing hyperthermia following the warm-up and through the fourth quarter. CMJ height was not significantly affected by the simulated basketball game. It was concluded that the increase in body temperature causing hyperthermia has an effect on the overall decline in lower extremity performance.

Basketball requires multidirectional movements that recruit the lower extremity musculature including; the CMJ, 10-m sprint and various short explosive movements such as a side shuffle. To perform at a high level, each movement requires powerful muscular contractions of the lower extremity.[29] 12-male Division 1 basketball players were tested on an isokinetic dynamometer at 180° and 60° knee flexion and then performed various agility drills (e.g. SJ, 10m sprint and T-test) to assess how peak power can result in better performance during the drills. The results show that the quadriceps peak and mean power output are positively correlated to an increase in mean power output at 180° (p<0.05) and 60° (p<0.05), but did not explain any other performance variables.[19] The findings provide a clear understanding on how important the quadriceps are to produce and maintain maximal power output.

The CMJ is a powerful movement in basketball that requires activation of the lower extremity musculature.[23] EMG data was collected previously on 12-female volleyball players who participated in CMJ and squat jump protocols. The biceps femoris (BF) showed to have a dominant effect during the eccentric landing phase of the CMJ (0.07±0.01 mV, p<0.05) and squat jump (0.08±0.02 mV, p=0.02), while having minimal effect on the concentric phase of the jump (0.03±0.01, p<0.01).[21] Bourne et. al., explained the importance of the hamstrings during the eccentric phase. 194 male rugby players were followed through their 2014 professional season. At the start of the 2014 season, each player was pre-screened through a Nordic hamstring exercise, an eccentric based exercise, assessing for power output. Power was assessed by the pull of the ankles during both the concentric and eccentric phases of the exercise. The season was then monitored, and the players were reassessed if a hamstring injury presented. 20 participants during the 2014 season had a hamstring injury and were utilized for the research. When retested, the affected hamstring was seen to be weaker than the contralateral limb at the start of the season by 50N (*p*<0.02) and subsequently weaker following injury. The CMJ and the Nordic hamstring exercise both recruit the hamstrings eccentrically. Because of this, hamstring strength and power is shown to be of importance when limiting lower extremity fatigue and injury.

The CMJ concentric phase was explained by Jakobsen et. al. 2012, to be quadriceps dominated. Jakobsens' research conducted on 49-male participants found that 12-weeks of strength training lead to more powerful CMJs. This backs the findings by Alemdaroğlu et. al., showing that the quadriceps must be strong and powerful to produce greater CMJ heights. Limiting the fatigue within these variables is a high concern for all basketball athletes due to the power demand of the lower extremity through the course of the game.

The purpose of this study is to determine the effect of intermediate cooling on CMJ height, 10m sprint time, RPE and perceived recovery score (PRS) during a simulated basketball game. The maintenance or improvement within each variable can show direct application into a basketball competition. Limiting or maintaining CMJ height or 10m sprint time, over the course of the game, could determine if the individual will grab a rebound or make a shot. These factors ultimately decide whether the team wins or loses a close game. When competing in a basketball game, time outs, rest breaks, and half-time breaks provide optimal time for intermittent cooling application. Intermediate cooling, applied during these breaks, can provide an option to stop the negative exercise effects seen during high-intensity aerobic activity such as basketball.

Instrumentation:

Each participant was equipped with a Polar HR monitor to evaluate the change in HR over each quarter of play. The Polar HR monitor (Polar Electro Incorporated, Bethpage, NY, USA) has been validated (*p*<0.01, r=0.97), showing small mean differences in HR variability when compared to the CardioPerfect 12-lead EKG (Nunan, D. 2009). Brower TC timing gates recorded participants 10m sprint times (TC, Brower Timing Systems, Draper, UT, USA).[33] A Just Jump mat (Probotics Inc., Huntsville, AL, USA) analyzed the CMJ height. Participants were analyzed based on the performance during the Basketball-Specific Fatigue Protocol (BSFP), which has been shown to induce in-game basketball fatigue with high reliability ($p<0.05$, r=0.92).[18,33] Cryotherapy was provided by four lower extremity PCM wraps or six wetted ice bags. The PCM wraps envelop the quadriceps, hamstring and calf musculature. These wraps are filled with a material that has been shown in previous literature to consistently cool and remain flexible at 15℃.[10,11] The secondary form of intermittent cooled used was WI and has seen to decrease temperature at the cutaneous level 14.2℃ from baseline while only 0.8℃ at the intramuscular level ($p<0.01$). Cutaneous tissue was also cooled at a significantly greater rate when using WI versus salted ice crushed and cubed ($p<0.01$)[2] The Borg rating of perceived exertion (RPE) 6-20 scale was used to assess the perceived difficulty of activity and has been validated has been validated to have significant correlation increase individual score as HR increases throughout dynamic exercise ($R^2=0.70$, $p<0.001$).[25,27,30]. RPE was presented to the participant on a visual analog scale with numerical markings from 6-20. This gave the individual the ability to either point or verbally que to a number. A 10-point PRS was assessed at the beginning of each quarter to evaluate the subjective recovery from the 5-minute intermittent cooling.[24] The 10-point PRS has been validated during high intensity exercise to be used interchangeably with the PRS 100-point scale (r = 0.95, p=.03) (Clemente, Rabbani, & Araújo, 2019). PRS was presented to the participants using a 0-10 point visual analog scale.