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The Cooling Effect of Cryotherapy on Power and Accuracy in the Pitching Arms of Baseball Players

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THE COOLING EFFECT OF CRYOTHERAPY ON POWER AND ACCURACY IN THE PITCHING ARMS OF BASEBALL PLAYERS

by
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This thesis would not be possible without God, who is always with me, nor without my family for their encouragement and support along the way. It is to them whom I dedicate my thesis.

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I would like to thank Dr. Dwight Waddell for guiding me in this study and my readers, Dr. Lucile McCook and Dr. Mark Loftin, for reviewing it. Additionally, I would like to express my gratitude to the test subjects who took part in the study for traveling to the test site and participating without reward.

ABSTRACT

DAVID KIMBLE WILBANKS: The Cooling Effect of Cryotherapy on Power and Accuracy in the Pitching Arms of Baseball Players
(Under the direction of Dr. Dwight Waddell)

As the human body does work, energy is released in the form of heat. The ability to perform the same action repeatedly and at the same intensity requires energy to be maintained. By preserving energy in sports, a reduction of injuries and an increase in performance duration would most likely be observed. More specifically in sports, for 200 years of baseball history, the pitcher has attempted to keep their arm warm during resting intervals of a game, in belief this would help sustain their level of performance. This study attempted to overturn this view.

I hypothesized that by cooling their arm between innings, pitchers' power and energy levels would be preserved and that their accuracy would be maintained. In this experiment, the levels of performance were quantified by measuring the velocity of a thrown baseball and recording whether it entered the target net. Players were observed and velocity recorded as they threw a set number of pitches and then rested with a thermoregulating upper body garment.

Three test subjects threw for five innings from a flat ground into a net behind home plate. Each inning the subject threw 17 pitches and then rested. During this 10.5 minute resting interval (average time of rest between innings), 8.5 minutes were used to

run chilled (≈ 8˚C) water through the garment, 1.5 minutes for water at normal physiological temperature (≈ 35.2˚C), and 0.5 minutes were used to put on and take off the garment. For the noncooling treatment, water at normal physiological temperature was run through the garment for 10 minutes.

Average pitch speed per inning for cooling and noncooling was compared along with an accuracy component of whether or not the pitch entered the net. For the first subject, cooling appeared to indicate that velocity decreased at a lower rate while accuracy was worse. For the second subject, the non-treatment seemed to elicit a slower decline in velocity over the pitched innings while the cooling treatment showed a higher rate of accuracy. However, the slopes of the lines of best fit for the velocity and accuracy graphs of the first and second test subjects fell within the standard deviations per inning, indicating no effect. For the final test subject, cooling did not demonstrate an effect for velocity or accuracy. In summary, this study did not illustrate a positive effect of cooling the arm during resting intervals to prolong endurance or accuracy. Another study involving more subjects with a sleeve made of a thinner material with a higher concentration of tubing in the arm, shoulder, and elbow area only would further evaluate the use of cryotherapy for pitching in baseball.

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CHAPTER 1: INTRODUCTION

In order for the human body to function, energy is required which is primarily obtained from food. As the body performs an action, energy is consumed and work is done. For the human body to continue to operate, its internal environment must be regulated around a physiological set point. This regulation within certain parameters is called homeostasis [1]. The boundary between the internal and external environments in multicellular organisms is formed by the integumentary systems [1]. Skin is a vital component of this system and in the regulation of homeostatic temperature. Although the core is sustained at approximately 37˚C, the skin is at a lower temperature because it represents a heat-loss surface area [1]. Without thermoregulation, the human body would eventually cease to function. Proteins would denature at high temperatures, affecting enzymes and cell function [27]. At cold temperatures, the rate of chemical reactions slows, and electrical signals in the heart and brain are reduced [1]. If the core temperature is reduced significantly, frostbite and hypothermia may occur [27]. If the body temperature continues to fall, the cardiac rhythm is affected leading to a slower heart rate, low cardiac output, and eventually ventricular fibrillation and death [27].

Cells metabolically produce heat in proportion to their metabolic activity [1]. Through higher physical activity, cells breakdown more nutrients for energy and thus produce heat. As heat increases, the hypothalamus recognizes this change in temperature and sends nerve pulses to effector tissues and organs to begin temperature regulation mechanisms [1]. The hypothalamus signals the smooth muscle in the arteriole wall to relax, causing vasodilation in skin blood vessels [1]. Blood is crucial in regulating temperature, and due to vasodilation, blood flow increases to the skin, allowing more heat to be lost [1]. Also as the core temperature rises, sweat glands are activated, allowing heat loss through the dissipation of energy through the vaporization of water [27]. A consequence of this is water and electrolyte loss [1].

Multiple studies have been performed on the relationship between cooling the body during physical activity and studying the effects on performance [2][3][5][6][7][11][12][16][17][18][24]. Assisting the body in thermoregulation would conceivably be a method to prolong endurance by lowering the increased temperature at a faster rate. This could be achieved by rerouting energy for thermoregulation signaling to energy for signaling an increase in blood flow to the muscle for the delivery of metabolites. Furthermore, by cooling the body faster, there would be less chance of dehydration due to a lower production of sweat.

Particular interest for prolonged performance involves athletes. Their ability to continually perform at the same level is important for success. Baseball is an interesting sport to study for assisted thermoregulation due to intermissions in action called innings. Innings are divided into halves and referred to as the “top” or “bottom” half. An athlete’s team is either on the field defensively or in the dugout offensively, presenting an opportunity for assisted thermoregulation. A sleeve with thin, flexible tubing could be attached to a device that pumps water through the piping. By covering the arm in cool water, for example, the arm’s muscles would be cooled, and the elevated temperature would be lowered faster. By achieving this sooner, the arm will perhaps maintain its ability to perform longer. This sleeve is of particular interest to pitchers whose arm strength endurance is significant for their career.

CHAPTER 2: BACKGROUND

2.1 Thermoregulation and Skin's Importance

As the body performs movement, heat is released, and after time, the body becomes fatigued. A possible mechanism for reducing fatigue involves the cardiovascular system [7]. As the body begins to become more active, blood flow to the skin is increased to dissipate heat. Therefore, blood flow to active muscle decreases, but the cardiovascular system is strained to account for the loss of flow [7]. As exercise increases, the body reaches a critical limiting temperature resulting in the subject reducing their exercise intensity or changing their pace to prevent cellular damage or sickness due to heat [6]. Since there is a maximum temperature that is reached which exceeding it would reduce performance, cooling the body would create a larger range before reaching the critical limiting temperature [6]. Due to this attempt to widen the temperature gap, cooling would be most effective in warmer conditions [6]. Cooling of the whole body and its correlation to performance in sport has been observed since the 1980s [7]. Since the majority of the baseball season is during summer, the warmer conditions would present an environment conducive to a cooling mechanism that could prolong endurance.

2.2 Cryotherapy

Booth, *et al*. showed that precooling may allow an athlete the ability to draw on energy reserves as the exercise time increases [2]. By maintaining the same intensity for a longer amount of time, endurance is shown. González-Alonso, *et al.*, indicated that by reducing the body temperature before exercise through cooling, the time to exhaustion is increased [4].

Cotter, *et al.*, studied precooling's effect on performance and endurance of cycling [16]. Furthermore in this study, localized cooling of the thigh was employed to study any additional benefits. It was concluded that precooling reduced physiological and psychophysical strain and increased endurance in moderately humid heat. Reduction in strain was observed through body temperature and cardiovascular strain measurements and further in heat discomfort, work effort, and body temperature. Cotter, *et al.*, found that strain and performance benefits were independent of localized cooling and suggested that cooling garments not be used on limbs where significant anaerobic work would occur. Although throwing a baseball occurs in a short burst of power and is considered mostly anaerobic, a study of cooling the pitching arm would either support or refute the suggestion of Cotter, *et al*.

Another study on cycling was performed by Marsh and Sleivert where they examined high intensity cycling after precooling [5]. Test subjects lay in cool water with their legs out of the bath. Their core temperature was significantly lowered from 37.2 ± 0.4˚C to 36.9 ± 0.4˚C without cooling the leg muscles directly. A power test was then conducted for 70 seconds; a significant difference between precooling and normal conditions was detected. Precooling led to a 3.3 ± 2.7% increase in power output. A possible explanation for this increase in power could be vasoconstriction of blood vessels in the other areas of the body besides the legs. This would allow for a greater central blood volume, therefore making more blood available to the exercising muscle. An increase in oxygen delivery and waste product removal would occur, leading to a greater power output.

In an additional study on precooling, Kay, *et al.*, examined self-paced cycling in warm humid conditions (31˚C and 60% relative humidity) [18]. Each cyclist (seven total from ages 18–31) rested for 30 minutes or was immersed in water for 30 minutes before their cycling trial. The immersion took place for the entire body excluding the head and neck in a bath of 29.7 ± 0.9˚C for 10 minutes. That water was removed and replaced with 8-11˚C water for approximately 60 minutes. The study found that after cooling, the distance cycled increased almost 0.9 km from 14.9 ± 0.8 to 15.8 ± 0.7 km. A key point of this study was that the skin temperature was reduced from the immersion, but the rectal temperature remained the same. This indicates that the shell of the body was cooled rather than lowering the core temperature and that cooling just the shell significantly improved cycling performance in warm, humid conditions. Not only were cyclists able to travel farther but there was also evidence of decreased cardiovascular and thermal strain. A possible explanation for increased performance given was that thermoregulation requires inputs from the outer level (skin) and core. Since skin is at a lower temperature, it requires more heat to build up before thermoregulation strategies take place. This would allow more metabolic energy to go toward performance rather than homeostasis.

Verducci performed a study using cryotherapy (cold treatment) on the shoulder, upper arm, and elbow of Division II nonscholarship players and measured innings pitched, velocity, and accuracy [17]. He studied six players' performances through two simulated games. He observed 100 professional games to find that, on average, 22 pitches were thrown over an eight minute inning that was then followed by eight minutes of rest. Following this pattern of time, each pitcher in his study threw three types of pitches (fastball, curveball, and changeup). They warmed up with seven pitches in the same order before each inning: fastball, fastball, curveball, fastball, fastball, changeup, and fastball. They were then allowed to pitch to three simulated batters five pitches each consisting of fastball, curveball, fastball, changeup, and fastball. Between each pitch, fifteen seconds were allowed with one minute resting intervals after warm-up pitches and each batter. During the eight minute resting period, either cryotherapy or the pitcher's normal technique was used. For cooling, three bags of ice, each one-third full of chipped ice, were applied to the shoulder, arm, and elbow for three minutes. Following the cooling, the pitcher covered their arm, shoulder, and elbow with towels for five minutes to allow for mild warming. In game situations, pitchers normally place their arms in jackets or some type of clothing to maintain the warmth of their arms for the entire resting period. The number of innings pitched, a reflection of endurance and the effects of fatigue, was dependent on how the pitcher felt based on three options: 1 = arm feels no fatigue, 2 = arm starting to fatigue, or 3 = arm is fatigued. Once the pitcher felt that they had reached level three, pitching concluded. After pitching, the shoulder and elbow were iced for 20 minutes. After statistical analysis, it was found that work increased by 26% during pitching, and velocity increased by 1.9 – 4.9% using cryotherapy with 83%

of the pitchers feeling less next-day soreness. The pitchers threw 26% more pitches after using cryotherapy, but their fatigue level was considered equivalent to when they used normal treatment because there was no significant difference between the velocities at level three fatigue of normal therapy versus level three fatigue of cryotherapy. This represents that the fatigue levels were approximately the same and that the pitcher was not straining to throw more pitches to support the cooling treatment.

In the previously discussed cooling study [17], bags of shaved ice were placed on the arm. It is difficult to evenly distribute this cooling over the entire area because bags, especially of ice and therefore water, tend to shift. Movement of the bags of ice would apply cold more to some areas and less to others. A possibility for solving this problem would be a device to spread the temperature equally over the surface area of the shoulder, upper arm, and elbow. This could possibly be achieved by way of a uniform pathway for a cool liquid to flow formed by tubing sewn into a sleeve or garment. This would expectedly cool evenly over the target area. A more efficient cooling system could possibly lead to more improved results than Verducci's findings.

2.3 Cooling Period Constraints

A concern with cooling, particularly at athletic events, is the time to cool an individual. Verducci points out that the time between innings needs to be considered [17]. It appears that direct immersion in water or the use of ice vests may be more efficient than cooling with cold air [6]. This would make cooling via a sleeve important and realistic for games. Finally, in her review, Domingues indicates that a short warming period of a few minutes be used after cryotherapy [3]. This could be achieved through the warm-up pitches that are given to the pitcher before each inning begins, by removing the cooling agent to allow air or natural body warming in the dugout, or by way of normal physiological temperature water piped through a garment over the cooled area.

2.4 Muscle Activity

Studies have been performed to analyze the electrical activity within a muscle called an electromyograph (EMG) [8]. EMG will increase with an increase in muscle tension due to additional motor unit recruitment or by increasing the frequency of firings by a motor unit [8]. This value has then been integrated and is referred to as iEMG. Cooling the muscle to 20˚C increased the iEMG signal during maximal and submaximal voluntary contractions [8]. However, when the muscle reaches temperatures below 20˚C, EMG amplitude decreases rapidly [8]. Different types of contraction reacted differently to the cold in this study [8]. Isometric muscle was able to endure longer under cold than dynamic. An isometric contraction occurs when a muscle contracts, but there is no change in muscle length [9]. In contrast, a contraction is considered dynamic when the length of the muscle changes. Endurance differences between isometric and dynamic muscle contractions can be attributed to differences in the use of ATP and reabsorption of calcium [8]. Isometric contraction requires less ATP than dynamic [8]. Muscle stiffens as a result of cold, further demanding more ATP by dynamic muscle to overcome this stiffness [8]. Another process that would affect endurance is the delay in reuptake of calcium by the sarcoplasmic reticulum ATPase in isometric muscle due to cooling of local muscle [8]. This would permit troponin-C to be exposed longer to calcium, allowing force to be maintained [8]. Drinkwater hypothesizes that rapidly cooling the skin in a short-duration could benefit short duration exercises that require very high power such as weightlifting or sprinting [8]. This would apply to pitchers who utilize short bursts of energy to throw a baseball.

2.5 Comparative Thermoregulation

Marino discussed the importance of thermoregulation and its link to performance through a paradigm [10]. He analyzed thermoregulation strategies of African hunting dogs, domestic dogs, and cheetahs and related these strategies to humans. The African hunting dog was an example of endurance and could be compared to humans who run long distance [10]. In contrast, cheetahs were examined and paralleled to human sprinters [10]. Although they remove heat in a nonevaporative way, the African dog can increase its core temperature whereas domestic dog keeps theirs approximately the same through respiratory evaporative means [10][11]. The African hunting dog's technique preserves water [10]. Humans can further thermoregulate beyond sweating upon an increase in core temperature from exercise by early termination of that exercise due to the ability to sense that further movement will lead to hyperpyrexia, when the core temperature rises to 40-42˚C and the possibility of irreversible damage to cells exists [10][12][14]. This is categorized as an early detection system. In a similar strategy, cheetahs store up to 70% of heat generated when they run, and at a certain point reach a limit that they will refuse to run [10][13]. Marino illustrated that in each mammal discussed (African hunting dog, domestic dog, cheetah, and human) there is a strategy for thermoregulation to prevent hyperpyrexia through knowing their physiological limit and avoiding cellular damage [10]. By attempting to assist natural thermoregulation through the use of a cooling treatment, endurance will theoretically be increased.

2.6 Heat Transfer

González-Alonso found in his study that more than one-half of the heat generated in an exercising muscle is liberated from the skin at the site of the muscle [15]. This is particularly interesting for studying cooling on the arm of a pitcher since the arm is under the most stress and experiences the most movement while throwing a baseball. Based on González-Alonso's study, more than 50% of the heat should be released from the arm. This allows for targeted cooling in a localized area that can be achieved by way of a cooling sleeve or garment that is in contact with the area producing the most heat.

2.7 Indication of Fatigue

In Fortenbaugh's, *et. al*., paper he compares fatigue to pain in that it is difficult to accurately measure since it is subjective and varies among individuals [21]. He suggests that through pitch counts, ball location and velocity, pitching mechanics, and strength one may be able to better quantify fatigue.

Murray, *et al.*, evaluated professional pitchers using two cameras and studied the angles of knees, elbows, and shoulders [19]. She found decreases in range of motion, torque, and force as the games went on and pitchers threw longer. It was unclear whether the decrease in range of motion, torque, and force was due to extended play and therefore fatigue, if it was related to a bodily mechanism to prevent injury, or both. In either case, a decrease in performance occurred.

In an unpublished study, three college baseball players with 47 reflective markers on their body threw 15 pitches over nine innings for a total of 135 pitches [20]. Their movement was recorded with eight cameras. Data indicated that as more pitches were thrown, fatigue increased, and the lower body was used less in the pitching motion. This places a greater reliance upon the arm to do more work. Greater dependence on the arm could lead to a higher output of localized heat [15] and possibly injury.

2.8 Prevalence and Prevention of Pitching-Related Injuries

A large study consisting of 476 pitchers from the ages of nine to fourteen was conducted over one baseball season [23]. Each team kept a count of the number of game pitches (excluding warm-up pitches and other throws). After each game, the pitchers were interviewed over the phone and questioned on how their arm felt and if there was any soreness, stiffness, or pain. Some pitchers were videoed, and their mechanics were broken down and rated. There was a total of 3789 appearances made by the pitchers. In 7% of these, elbow pain was reported while shoulder pain was reported in over 9% of the appearances. Over the course of the season, 28% of the pitchers said they felt elbow pain at least once during the season while 35% reported shoulder pain. In summary, shoulder or elbow pain was felt in almost 15% of all appearances with 50% of the pitchers reporting elbow or shoulder pain at least once during the season. In addition to the pitch count, the type of pitch was recorded. In pitchers that threw sliders there was an 86% increased risk of elbow pain while those that threw a curveball indicated a 52% increased risk of shoulder pain. Elbow or shoulder pain in young players could be a sign that an injury may occur from overuse. Muscle soreness is expected when exercising, but joint pain was of particular concern in this study.

Different types of preventive measures were suggested in this study [23]. There was a 12% reduction in risk of elbow pain and 29% reduction in risk of shoulder pain by throwing a changeup, indicating that changeups should be used more than breaking pitches. Another suggestion for preserving young arms is either a pitch limit or batter limit instead of an inning limit where a high volume of pitches could still be performed. A batter limit was suggested over a pitch limit to prevent opposing teams from taking pitches and waiting for a pitcher to be removed from a game. The study pointed out that although high amounts of pitching led to an increased chance of joint pain, practice is important for young pitchers. Pitching infrequently could harm the pitcher whereas drills help develop a pitcher's coordination, flexibility, strength, endurance, mentality, and other skills. Furthermore, proper pitching mechanics are necessary to alleviate joint pain associated with throwing. In summary, use of the changeup, reduction of pitch counts through a batter limit, and proper practice and mechanics could reduce elbow and shoulder pain in young pitchers [23].

Beyond these preventative measures, cryotherapy could possibly be employed to further prevent injuries to the arm. Currently, one of the major topics of concern is overplaying and overpitching young players, some damaging their arms irreparably.

Overuse can ruin future dreams at an early age. The cooling technique could possibly be applied early in the development of baseball players to reduce injuries and to also maintain performance when they play.

Pitchers are arguably the most important player on the field since all action in baseball is initiated by them throwing the ball. They are relied on to win games for their teams, especially if their team struggles to score runs. Therefore, pitching can win or lose championships and is more trustworthy than relying on hitting long term. When examining playoffs for teams, the first item of observation is the pitching rotation, starting pitchers who will be used during the most important games of the season. The second observation is the bullpen, pitchers who come in to relieve the starters. In Major League Baseball, teams spend millions of dollars on pitchers in an attempt to solidify their lineups. For example, Clayton Kershaw in 2014 signed a seven year contract worth $215 million [24]. This gives him the largest contract for a pitcher ever and currently the highest average annual salary in Major League Baseball [24]. With this type of investment, a pitcher’s endurance is one of their most important attributes. By being able to throw longer and maintain their dominance, pitchers can account for weaknesses in the team. Repeatedly doing this year after year can lead to a pitcher becoming one of the most sought after players.

“America’s favorite pastime,” baseball, has been played for hundreds of years. Techniques and routines have been developed that may not always be the best for the players. As we advance in technology, changes may need to be made to player treatment. Pitchers placing their arm in a sleeve to warm their arm may no longer be the solution to benefit their pitching performance. Cooling the arm to increase the margin from the critical limiting temperature and to reduce blood flow to the skin to reduce cardiovascular strain will hopefully increase pitching endurance. If blood can be rerouted to nourish muscles with metabolites rather than used for thermoregulation, muscular endurance and performance can be increased and preserved. The outcome of this cooling experiment could have changed how pitchers have been treating their arms for hundreds of years. This would have potentially impacted financial investments in higher levels of baseball and protected goals of younger players through injury prevention and higher performance.

CHAPTER 3: METHODS AND MATERIALS

This experiment was carried out in a before-after (crossover) experimental design. Each test subject acted as their own control group by measuring without application of cooling and then after cooling. An unpublished study from Tulane University has been performed similarly and contains averages for pitches thrown per inning, time of rest per inning, and other averages for college pitchers [24]. The study found that each inning lasted on average 10 minutes and 34 seconds with approximately 17 pitches per inning.

My study targeted slightly younger athletes, particularly at the high school level. Although high school games last fewer innings than college (seven vs. nine respectfully), the pitcher in the unpublished study only threw for four to five innings. In my study, pitchers threw 17 fastballs per inning for five innings, giving a total of 85 pitches. In high school, a pitcher has 60 seconds or up to 7 pitches to warm-up [25]. In this study, two warm-up pitches were performed before the "game pitches" were studied. The pitchers threw on flat ground from 60 feet 6 inches, the distance from the pitching rubber to home plate [26]. Pitchers were randomized in that some initially threw with the cooling treatment and some without. They returned two weeks later to throw using a different treatment from their previous experience. The number of pitches they would be throwing was not revealed to them. This was an attempt to reduce outlier readings by an increase in effort on the last pitch by the player.

The garment for this experiment covered the upper body including the shoulder and arm down to the wrist. It was a suit designed by Med-Eng™ for military use in a desert environment and particularly in tanks to help withstand high temperatures. Small flexible tubing is sewn into the flexible fabric allowing water to be piped throughout the garment, applying the temperature of the water superficially. The garment was worn on both days of measurement. On the day of the cooling treatment, the pitcher rested with chilled (≈ 8˚C) water running through the sleeve for 8.5 minutes [24]. For the remaining two minutes of the interval, normal physiological temperature water (≈ 35.2˚C) was piped through the sleeve for 1.5 minutes, leaving 0.5 minutes for changing equipment [24]. On the noncooling treatment day, the pitcher rested for 10 minutes while normal physiological temperature water was channeled through the garment. Performance and endurance were quantified through pitch velocity and accuracy gauged through the use of a net with a hole in the center. The speed and accuracy of the pitches were recorded, compared, and analyzed statistically. The time-frame from beginning to end of this study was two weeks.

CHAPTER 4: RESULTS

The average pitch speeds per inning were graphed for the cooling and noncooling treatments. Slopes of the lines of best fit were then compared for treatment effect. In addition, percentages of strikes per inning were graphed and slopes of the lines of best fit compared for cooling and noncooling. A strike occurred when the ball entered the hole in the center of the net. Below are the graphical results of cooling and noncooling treatments on the component of pitch speed.

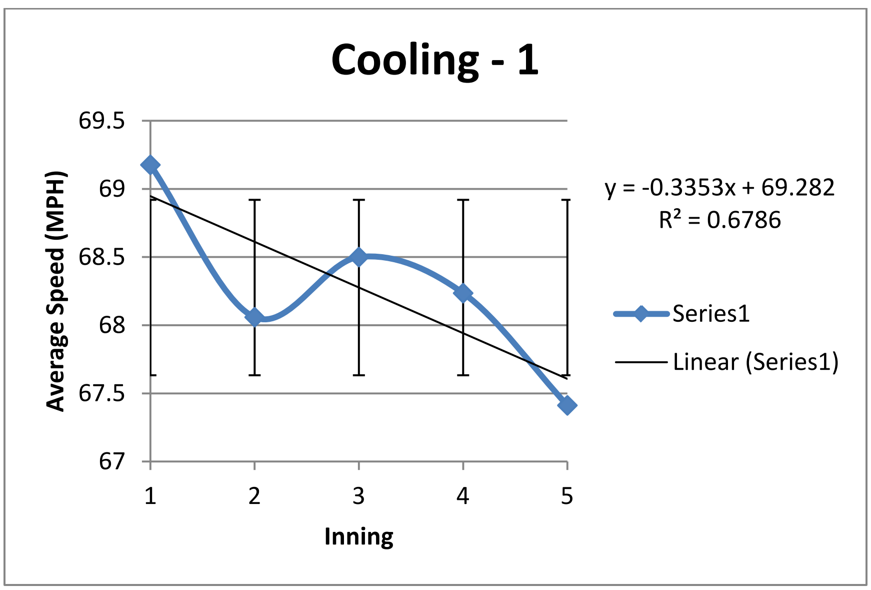

Figure 1: Average speed results of the first test subject with cooling treatment.

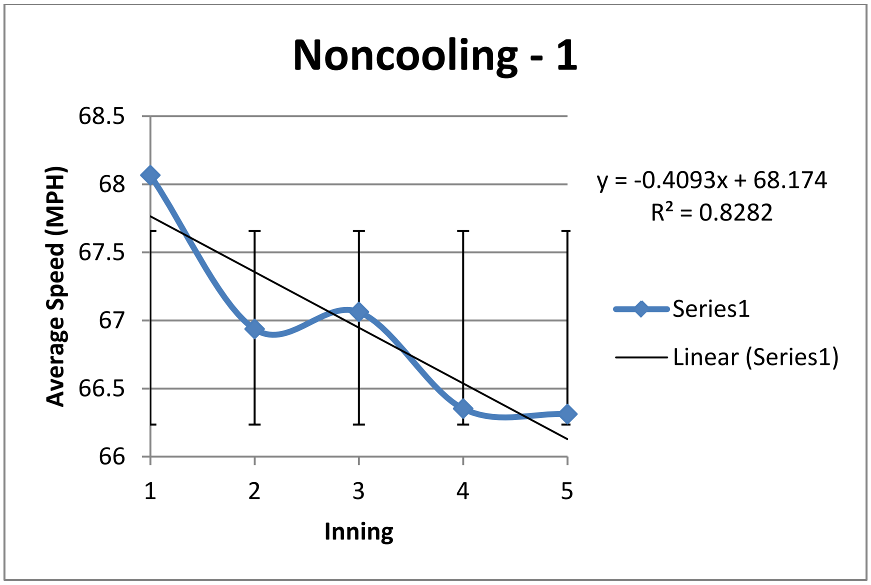

Figure 2: Average speed results of the first test subject with noncooling treatment.

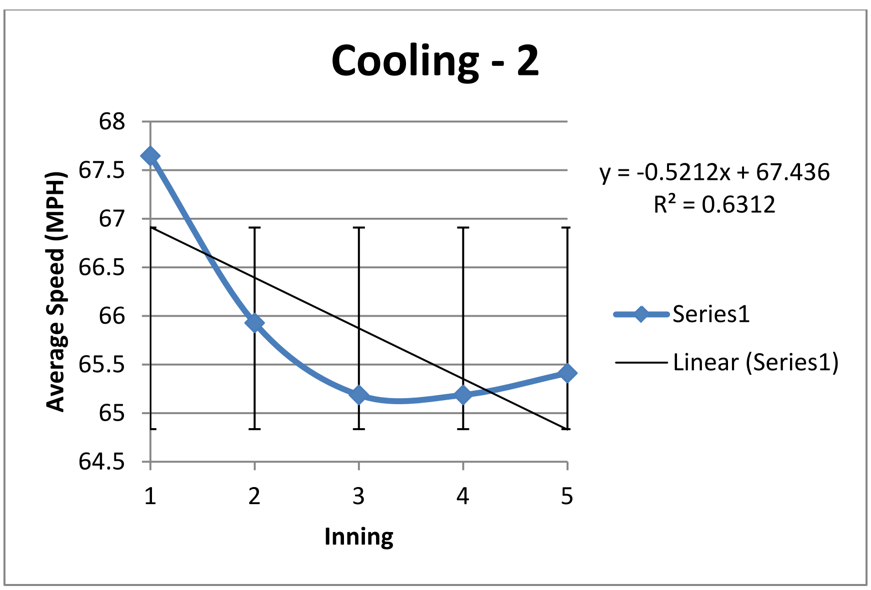

Figure 3: Average speed results of the second test subject with cooling treatment.

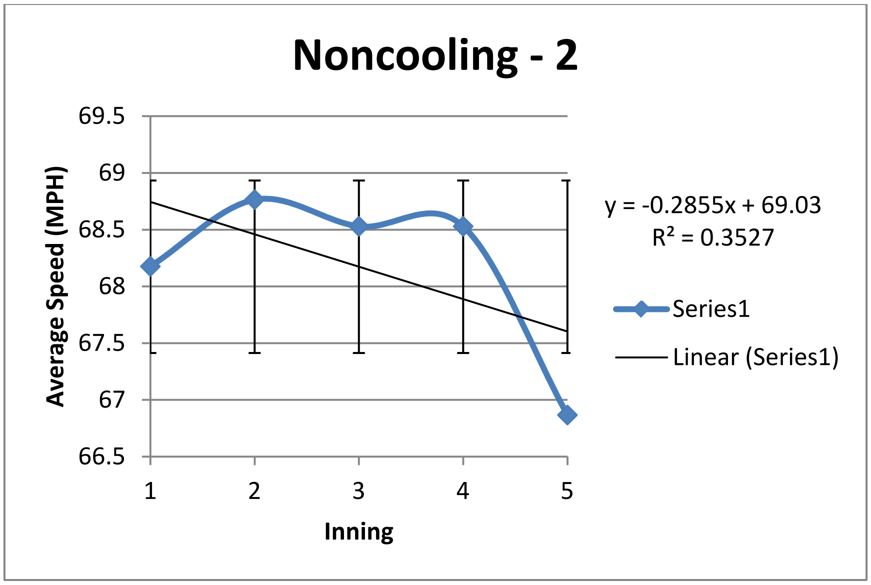

Figure 4: Average speed results of the second test subject with noncooling treatment.

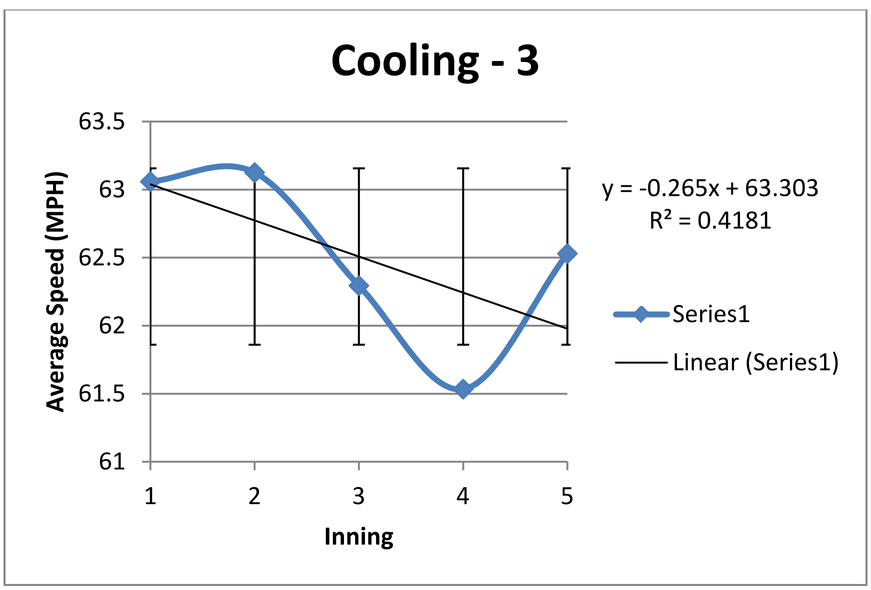

Figure 5: Average speed results of the third test subject with cooling treatment.

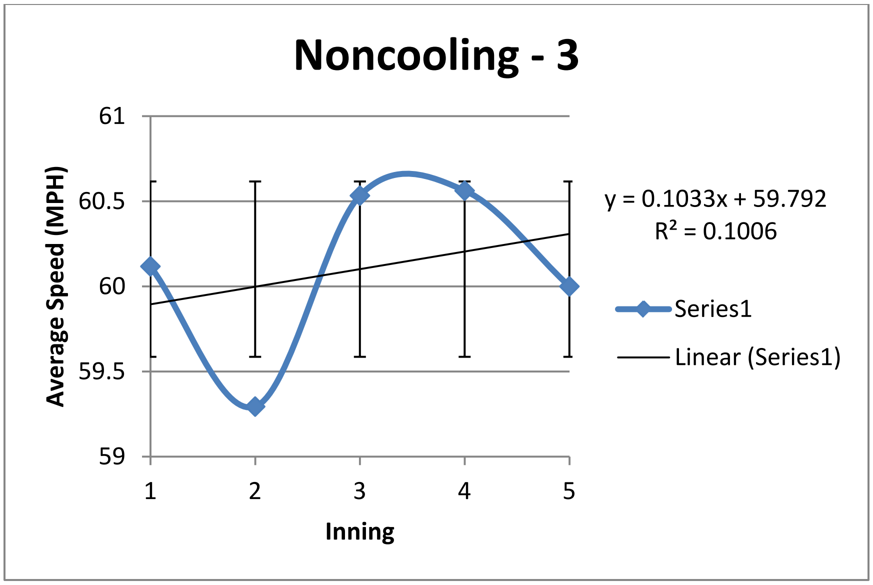

Figure 6: Average speed results of the third test subject with noncooling treatment.

The average speed was plotted per inning. The lines of best fit were created for these graphical points, and the slopes of these lines were used to evaluate the treatment effect (Table 1). A more positive slope indicates a lower rate of decline in speed over innings pitched demonstrating a greater endurance. A possible treatment effect for the first test subject is revealed by the slope, but it falls within the standard deviation of the speed for the innings. The other test subjects do not demonstrate an effect on speed from the cooling treatment.

Table 1: Slope of average pitch speed per inning for cooling and noncooling treatments.

Test Subject	Cooling Slope	Noncooling Slope
1	-0.3353	-0.4093
2	-0.5212	-0.2855
3	-0.265	0.1033

The percentage of strikes thrown per inning was also plotted. The slopes of the lines of best fit for these graphs were compared to evaluate the accuracy component of cooling versus noncooling. Below are the graphs that were constructed to analyze accuracy. Table 2 summarizes the slopes for these graphs and shows no effect of cooling on accuracy for the first and third test subjects. The second test subject's accuracy increased with the cooling effect. More on this test subject is discussed in the next chapter.

Table 2: Slope of strike percentage per inning for cooling and noncooling treatments.

Test Subject	Cooling Slope	Noncooling Slope
1	-8.2353	-3.8211
2	6.5809	-4.4706
3	-3.8946	0.3309

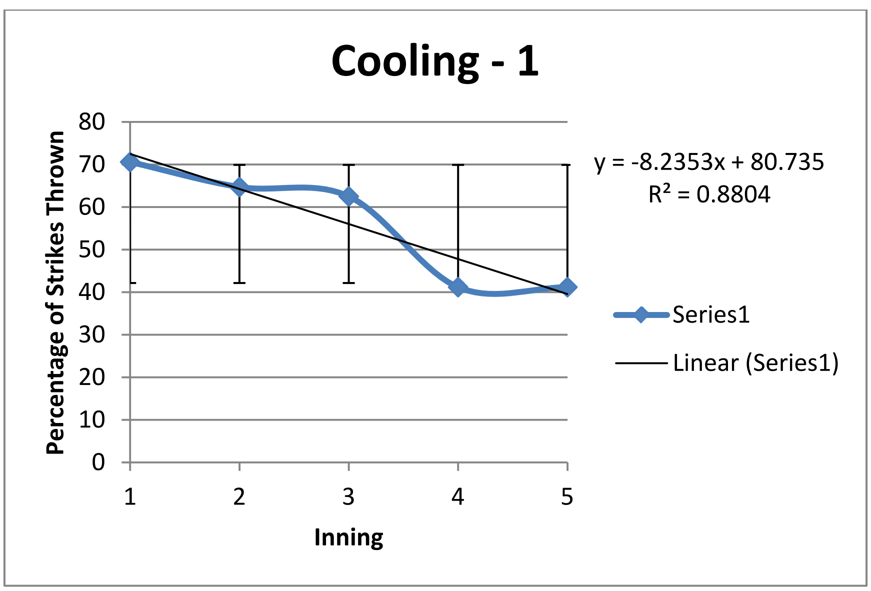

Figure 7: Strike percentage of the first test subject with cooling treatment.

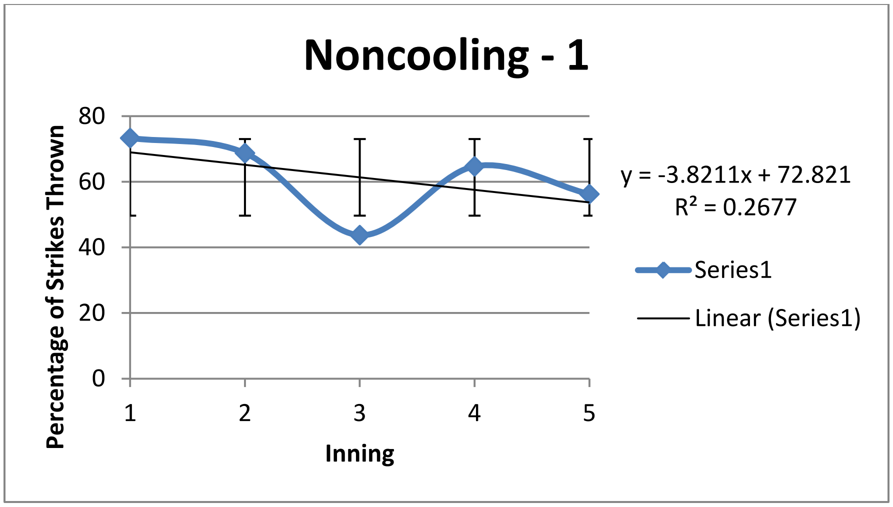

Figure 8: Strike percentage of the first test subject with noncooling treatment.

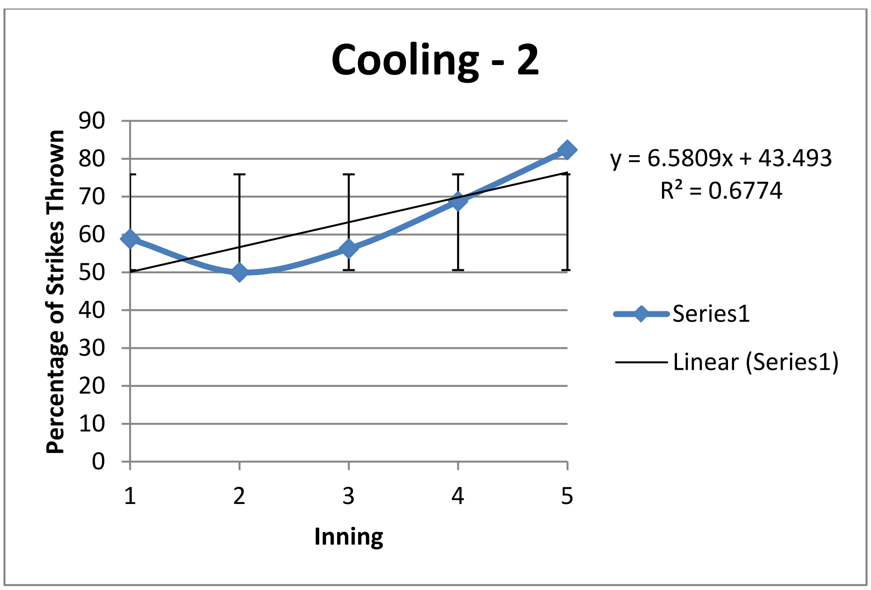

Figure 9: Strike percentage of the second test subject with cooling treatment.

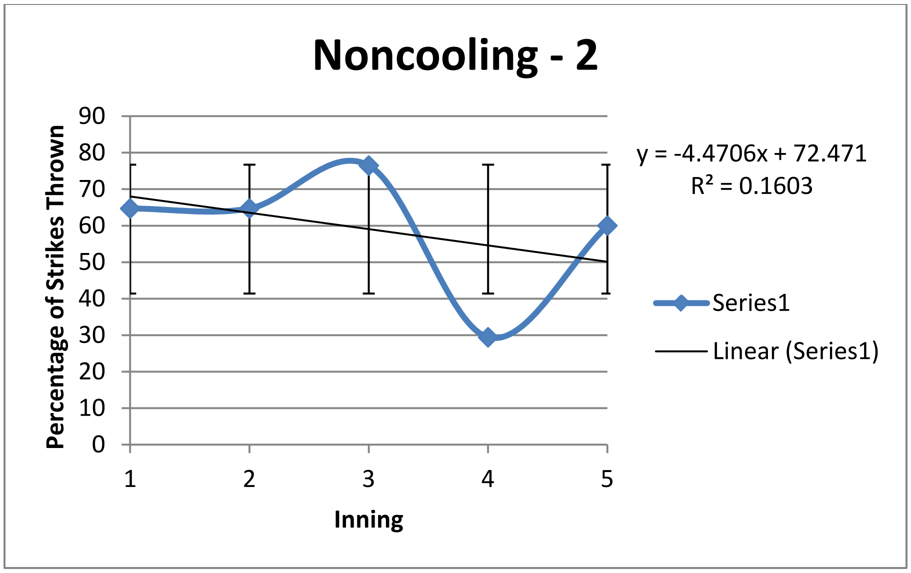

Figure 10: Strike percentage of the second test subject with noncooling treatment.

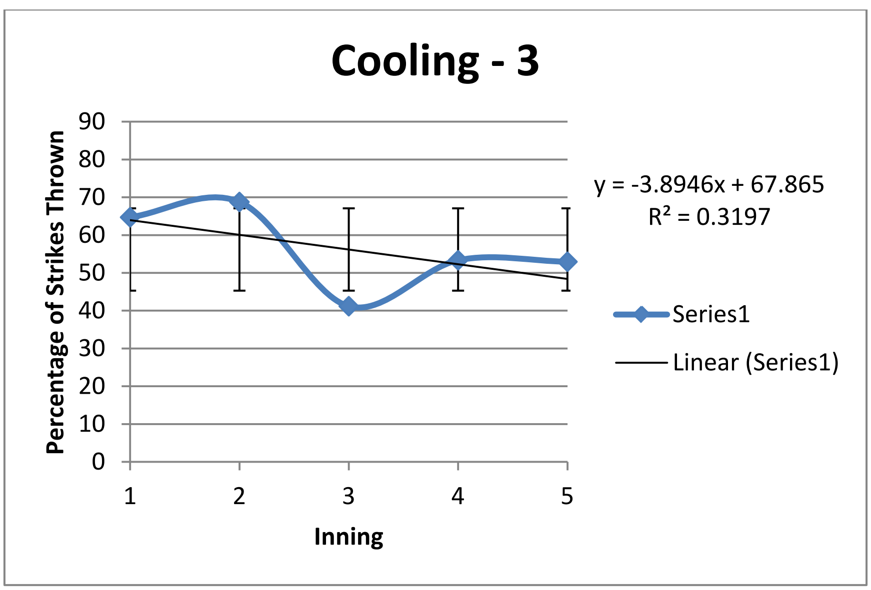

Figure 11: Strike percentage of the third test subject with cooling treatment.

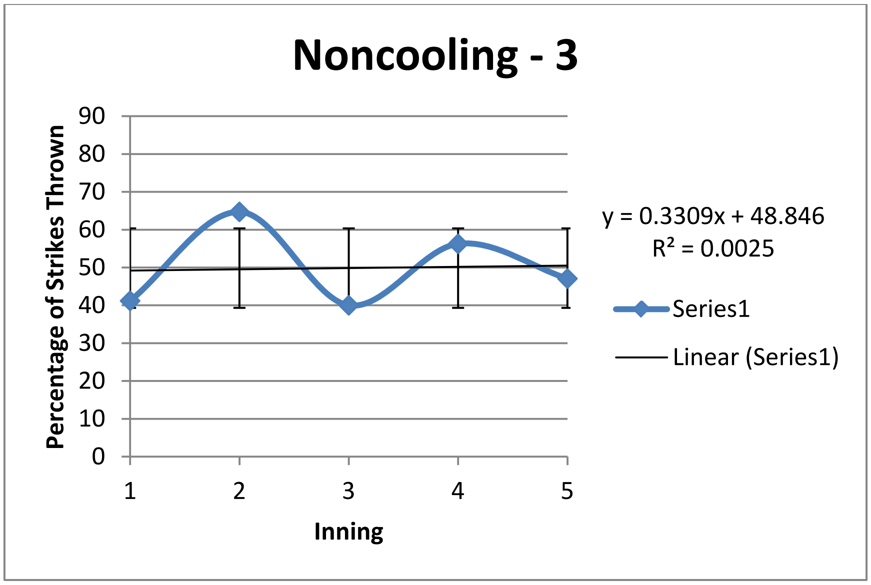

Figure 12: Strike percentage of the third test subject with noncooling treatment.

CHAPTER 5: DISCUSSION

The study performed included three test subjects of the high school baseball level. The first pitcher seemed to indicate the hypothesized effect of the cooling treatment maintaining endurance by average pitch speed per inning declining at a lower rate than the noncooling treatment, but it was not an effect greater than the standard deviation. However, the other two subjects demonstrated the opposite effect. Their average pitch speed per inning decreased at a higher rate with the cooling treatment but not beyond the standard deviation. The second test subject mentioned some shoulder soreness and elbow pain due to throwing a high number of pitches four days prior to the day he was observed with cooling treatment. When asked on numerous occasions, he indicated that he was able to continue pitching. This however could have affected his velocity and therefore his data.

The accuracy component was supported by the second test subject's data where the accuracy went beyond decreasing at a lower rate and actually increased over the innings pitched with the cooling treatment. This test subject however was experiencing soreness, and the accuracy could have been improved by the removal of lactic acid through muscle activity as the innings progressed. Another aspect to consider is the possibility of the cooling treatment helping to remove the lactic acid by replenishing the muscle with metabolites since the blood could be rerouted to the muscle rather than to the skin for thermoregulation. The other test subjects' data did not support the hypothesis and showed a decline in accuracy at a higher rate with cooling rather than noncooling treatment but not beyond the standard deviation.

The exact reason why cooling did not have the hypothesized effect is unclear. Murray, *et al.*, noted a 2 m/s (5 mph) decrease in fastballs over studied games [19]. In this study, the velocity in the first inning and last inning did not decrease by 5 mph for any subject under cooling or noncooling treatment. The effect of cooling may be masked if there is only a slight decline (< 5 mph) in pitch speed for either treatment. This could indicate the test subjects were not pitching at full power, reducing the effect of fatigue on their arm, thereby preventing any noticeable effect of a cooling treatment.

In addition, it is possible that there was not enough surface to surface contact between the tubing and the skin, preventing proper cooling. Another potential aspect reducing the cooling effect is the temperature of the chilled water. The water temperature could possibly need to be lower to create the hypothesized effect. A final explanation for the ineffectiveness of the cooling treatment is that the body may simply have not responded to the experimental treatment at all and continued to direct blood to the skin for thermoregulation rather than to the muscle for nourishment.

CHAPTER 6: CONCLUSION

The study indicated no effect of cooling on endurance and accuracy. However, it is suggested that the study be recreated with a larger sample size and more rigid control of test subjects between data collections. Studying subjects who have not had strain on their arm days before collecting data would be ideal. In addition, constructing a sleeve that is made of extremely thin material to increase the application of cold could possibly influence the results. Moreover, the use of a sleeve with a higher concentration of tubing over the shoulder, arm, and elbow region would increase the amount of surface contact by the chilled water, thereby applying cooling to a greater surface area in a more consistent method. Furthermore, if a study could be created in a high humidity, high temperature environment, fatigue would be more induced, presenting an opportunity for a greater effect by a cooling treatment. These aspects could potentially lead to positive effects on endurance and accuracy through cooling.

If the cooling effect occurs, this cooling system could be used during games. Ideally, the material and the tubing would be flexible enough to be worn under the uniform without having to put on and take off a cooling garment, allowing the cryotherapy to begin faster and leading to more time under treatment. Further testing is required and suggested to explore the effect of cooling at a greater extent.

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