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Effect of Warm-Maintenance Between Innings on Overall Pitching Performance

Ian Lockwood
Ithaca College

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EFFECT OF WARM-MAINTENANCE BETWEEN INNINGS ON OVERALL PITCHING PERFORMANCE

A Master's Thesis presented to the Faculty of the
Graduate Program in Exercise and Sport Sciences
Ithaca College

In partial fulfillment of the requirements for the degree
Master of Science

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by

Ian Lockwood

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Ithaca College
Graduate Program in Exercise and Sport Sciences
Ithaca, New York

CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Master of Science Thesis of

Ian Lockwood

submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Health Sciences and Human Performance at Ithaca College has been approved.

Thesis Advisor:

Committee Member:

Candidate:

Chair,
Graduate Program:

Dean of Graduate Studies:

Date: 8/11/09

ABSTRACT

This study examined if pitchers who performed warm-maintenance (WM) using treadmill walking and arm circles between innings maintained better ball velocity and accuracy than using only a traditional warm-up (NWM). Collegiate pitchers (N = 7) pitched four simulated innings on two different occasions. During NWM, each pitching stint was followed by a sham treatment involving brief, light treadmill walking at 15% HRR (93.1 ±12.7 bpm) and then seated rest. During WM, pitching followed the same pattern of activity, however instead of seated rest subjects performed arm circles and walked on a treadmill at 45% HRR (128.1 ±2.8 bpm), for each entire half-inning. Innings consisted of 15 pitches, with fastballs thrown on pitches 1-3, 7-9, and 13-15, which were evaluated for velocity and accuracy. Performance readiness and shoulder external and internal rotation were evaluated before each inning. Velocity and accuracy were each analyzed by using a 2x3 ANOVA (Treatment x Trial) for each inning, with repeated measures on both factors. For performance readiness, dependant samples t-tests were used to analyze between condition effects of each inning. Pitching arm range of motion was analyzed using a 2x2 ANOVA (Treatment x Rotation) for each inning, with repeated measures on both factors. The significance level for all statistical analyses was set at $p < 0.05$. The results showed that there was no significant difference between WM and NWM, with respect to pitching velocity, accuracy, or performance readiness. However, performance never significantly declined due to the effects of WM. There were no significant differences in pitching arm shoulder range of motion. Although WM did not improve performance, the fact that velocity and accuracy can be maintained with the use of WM, pitchers and coaches might want to reconsider the current sedentary approach typically practiced between innings.

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DEDICATION

I would like to dedicate my master's thesis to my parents, whom have been my biggest supporters throughout my college years. Their unwavering support, patience, and encouragement, even when they had no idea what exactly exercise science entailed, has meant more to me then they realize. I am incredibly grateful, and consider myself lucky to have parents who have given me the opportunity to find my own unique profession, rather than suggesting I follow a more traditional college major and career path. To this day, I am still excited about pursuing a career within strength and conditioning, and I have only my parents to thank for that. Thanks Mom and Dad.

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Chapter 1

INTRODUCTION

The need for a warm-up before competition is a generally accepted concept among athletes and coaches. A warm-up is meant to prepare an athlete to compete, both physically and psychologically, and should ideally carry over into the start of competition. A proper warm-up should allow an athlete to start competition at an optimally functioning level, to be maintained throughout the length of competition. A warm-up is considered any purposeful exercise conducted before performance, regardless of elevation of muscle or body temperature (Powers & Howley, 2004). To begin a competition without having first thoroughly warmed-up would seem unacceptable to most athletes, however, many athletes start a competition sitting on the bench or sit during the game for an extended period of time. Typically warm-ups are done before competition, and not much thought or effort is given to maintaining warm-up once competition has begun. A period of non-activity creates a potential problem for the athlete whose sport requires alternating patterns of rest and exercise, such as football or baseball, making the warm-up effect difficult to maintain.

Warm-up may have a positive effect on performances of short-durations. Improvements in short-duration performance due to warm-up are thought to be a result of decreased muscle and joint stiffness by breaking actin-myosin bonds which increase with inactivity, increased transmission rate of nerve impulses, and changes within the force-velocity relationship (Bishop, 2003). Pitching a baseball is a short-duration performance that may be affected by warm-up.

Pitchers are repeatedly required to perform full-body, dynamic, powerful motions through use of the kinetic chain in order to throw at high velocities with great accuracy. These repeated intervals of powerful movement are then followed by periods of rest generally of similar length. While rest can be beneficial, rest of extended durations, such as sitting for 10 to 15 min between innings, may cause detrimental performance effects. Presently, it is common to see pitchers wearing a jacket over their pitching shoulder between innings, suggesting the importance of keeping their arm warm. This is followed by the traditional warm-up for a pitcher of several practice pitches with each practice pitch increasing in intensity. Warm-up before a game could be any number of modalities, from light jogging, throwing, calisthenics, resistance tubing, or a variety of other familiar practices. These traditionally practiced warm-ups are insufficient for eliciting game-long benefits such as increasing muscle temperature, decreasing joint stiffness, increasing blood flow, increasing nerve transmission rate, and increasing overall readiness to pitch.

Given the nature of the pitching motion it would seem that a maintained warm-up used to increase body temperature, improve speed and efficiency of muscle activation, while also decreasing stiffness around the major joints would potentially have a positive effect on pitching performance. Therefore, the purpose of this study was to determine if pitchers who performed warm-maintenance (WM) between innings improved ball velocity and accuracy during a simulated game.

Scope of the Problem

Baseball is a sport with international appeal that is played by young and old, recreationally and professionally. Pitching is a critical component to a baseball team's success and there is very little research on techniques to improve pitching performance.

The periods of rest between innings could be potentially detrimental to pitching performance, particularly early in an inning, if the body was allowed to cool, joints stiffen, or readiness was lost. As a result, the two keys to pitching, velocity and accuracy, could diminish and performance may suffer. It would seem that proper WM between innings is warranted, however with baseball strongly rooted in tradition, WM for pitchers is rarely practiced. A "warm-up" for pitching is typically a few practice pitches, which likely does not warm the body at all. There are no studies that have evaluated the effect of seated rest on pitching performance and the results of this study could be of interest to pitchers and coaches at all levels who are looking to improve performance.

Statement of Purpose

The purpose of this study was to determine if pitchers who performed warm-maintenance (WM) by using treadmill walking and arm circles between innings maintained better ball velocity and accuracy throughout a simulated game than when using only a traditional warm-up.

Hypothesis

The hypotheses for this study are:

1. Ball velocity and accuracy will be better for the treatment condition, particularly at the beginning of each inning (first three pitches), compared to the control condition.
2. Performance readiness at the start of each inning, as measured by a 1 to 7 readiness scale questionnaire, will be better for the treatment condition, compared to the control condition.

3. Shoulder range of motion will be greater during the treatment condition, compared to the control condition.

Assumptions of the Study

For the purpose of this study, the following assumptions will be made at the start of the investigation:

1. Velocity and accuracy are the two main components to successful pitching performance.
2. The subjects will follow instructions given by the investigator and maintain an optimal balance between maximal pitching velocity and accuracy to the best of their abilities.
3. The majority of collegiate pitchers sit and do not stay active between innings.
4. Acute physiological effects of pitching immediately begin to recover after the last pitch of each inning.

Definition of Terms

The following terms are operationally defined for the purpose of this investigation:

1. Warm-up - any form of exercise, movement pattern, or modality done before activity in an attempt to ready the body for performance.
2. General warm-up - activity that serves to increase heart rate, blood flow, muscle temperature, respiration rate and perspiration, while decreasing the tissue and joint fluid viscosity (Holcomb, 2000).
3. Specific warm-up - activity that involves motor patterns that closely mimic the activity to be performed (Holcomb, 2000). These may or may not induce physiological effects of a general warm-up.

4. Warm-up decrement - a decrease in performance when activity resumes after a given interval of time, such as bench rest or between a warm-up and the start of competition (Anshel & Wrisberg, 1993). Can occur during competition or pre-competition if a warm-up includes a sport/motor pattern specific component, which is followed by minutes of inactivity.
5. Warm-maintenance - a general and/or specific warm-up used to overcome periods of rest once performance has begun in order to maintain optimal readiness.

Delimitations

The delimitations of this study are as follows:

1. The subjects were limited to collegiate pitchers between the ages of 18 and 21 years with no known recent injuries.
2. All testing was performed indoors in a simulated pitching setting, with a constant environmental temperature between 68-70°F.
3. No catchers, batters, or umpires were used for the pitching simulation.
4. Rate of pitching was every 25-30 s with only 15 pitches per inning and a limit of four innings.
5. Pitching accuracy was measured with the use of a stationary, rectangular strike zone, with targets in each of the four corners.
6. The warm-maintenance involved treadmill walking and arm circles at 45% HRR for about 7.5 min.
7. Performance readiness was measured through the use of an adapted question from the Children's Arousal Scale (CAS), with score ranging from 1 to 7.

Limitations

The limitations of this study are as follows:

1. The results of this study may not be generalized to:
    1. Pitchers with musculoskeletal injuries or who are substantially older or younger than those used in this study.
    2. A live outdoor, baseball, game environment with different climatic conditions and consequential situations.
    3. Innings that last longer than 15 pitches or later innings in a game (i.e., 5-9).
    4. Other sports (e.g., the different motion of a softball pitch).
    5. Other methods for evaluating pitch accuracy or measuring pitch movement.
    6. Other warm-ups of different intensity, duration, or type.
    7. The adapted question from the Children's Arousal Scale (CAS) may not entirely measure performance readiness in the way it was intended.

Summary

A great deal of previous research has been devoted to pitching biomechanics, overuse injuries, and structural imbalances, however no research has attempted to improve overall pitching performance using a warm-up effect. It is apparent that a lack of thought, effort, and research has been devoted to maintaining warm-up once a baseball game has begun. The powerful nature of pitching, paired with the plethora of research studying the positive effects of warm-up, provides a reason to believe that maintaining warm-up between innings, may improve pitching performance. The purpose of this study was to examine this hypothesis.

Chapter 2

REVIEW OF LITERATURE

Introduction

Warming-up is an integral part of most athletes' preparation before competition, however little consideration is given to warm-maintenance (WM) once competition begins. Pitching motions (i.e., baseball and softball) are a cyclic, full body, power movement that should benefit from WM rather than intermittent inactivity, however little is known about this idea. Therefore, the focus of this chapter will be to review the research on warm-up and how it may relate to pitching performance. This includes the types of warm-up, physiological effects of warm-up, warm-up and stiffness, and approaching warm-up for short and intermediate-duration performances, varying warm-up intensity, duration, and recovery will be discussed as will the psychological effects of warm-up. In order to evaluate the effect of WM on performance, an understanding of how pitching can be quantified must also be considered. Thus, a final part of this chapter will focus on evaluating throwing velocity and accuracy.

Warm-up

Types

The term warm-up does not necessarily connote temperature-related changes within the body, however many of the benefits associated with warming-up are due to the acute temperature response to increased activity. According to the National Strength and Conditioning Association (Holcomb, 2000), a "general" warm-up of light to moderate activity will serve to increase heart rate, blood flow, muscle temperature, respiration rate and perspiration, while decreasing the tissue and joint fluid viscosity. A "specific" warm-up involves motor patterns similar to the activity to be performed, such as practice pitches before an inning. Temperature-related changes are typically a result of general warm-up, however passive warm-up (e.g., water baths, saunas, diathermy, and heating pads) is also an option, although somewhat inconvenient for athletes. The benefit of a passive warm-up is an increase in muscle and core temperature without taxing energy substrates as during an active warm-up.

Passive warm-up before short-duration (<10s) maximal effort performance can improve dynamic force and may potentially increase power by about 5% per °C of muscle temperature (Bishop, 2003). Increased muscle temperature, as a result of passive warm-up, increases all aspects of the force-velocity relationship, except maximal isometric force (Binkhorst, Hoofd, & Vissers, 1977). Davies and Young (1983) found that passively increasing muscle temperature by 3.1°C decreased the electrically-evoked time to peak tension (7.7% per °C) and half-relaxation time (7.2% per °C). Muscle temperature changes also affect maximal velocity of muscle shortening (2.6% per °C) and maximal power (5.1% per °C) (Binkhorst et al., 1977). Additionally, Sargeant (1987) found that passively heating or cooling the legs influences maximal peak force and power during a 20 s isokinetic cycle sprint. By using water baths to warm the legs to 39.3°C, maximal peak force and power increased by about 11% while cooling the legs to 31.9 and 29°C resulted in decreases of about 12 and 21%, respectively. Changes in force and power were compared to legs at room temperature, which was 36.6°C. Given the powerful, single-effort, cyclic motion of pitching, these kinds of improvements in muscle contraction could potentially be beneficial. In addition, passive warm-up may increase the rate of ATP turnover, correlating to an increase in mean power output (Gray, De Vito, Nimmo, Farina, & Ferguson, 2005). Passive warm-up is not always convenient for athletes and may best be used to sustain muscle temperature between bouts of active warm-up and a short-duration performance. Results similar to passive warm-up can be achieved with the use of an active warm-up as well.

Active warm-up involves the use of exercise and causes effects that can be divided into two groups: temperature-related changes and non-temperature-related changes. Temperature-related mechanisms are directly related to relative work load and consist of faster nerve conduction rate, increased release of oxygen from hemoglobin and myoglobin, increased speed of metabolic reactions, and decreased resistance of muscles and joints (Bishop, 2003). Increased muscle temperature alone has been shown to improve performance, while increased rectal (core) temperature changes only have a minimal performance effect (Asmussen & Bøje, 1945). Non-temperature related effects of warm-up consist of increased blood flow to muscles, elevated baseline oxygen consumption, possible postactivation potentiation, and psychological effects such as increased preparedness (Bishop, 2003).

Physiological Effects of Warm-up

Contractile Properties and Nerve Conductivity

Increased muscle temperature may improve nervous system function as it relates to muscle contraction as it will enhance central nervous system function and the transmission speed of nerve impulses (Bishop, 2003). During a 6 s maximal cycle sprint, ATP turnover and muscle fiber conduction velocity (MFCV) were increased with elevated muscle temperatures (Gray et al., 2005). The increase in MFCV is likely due to a temperature-mediated effect on voltage-gated sodium channels.

> At higher temperatures, the opening and closing of these channels accelerate, allowing less Na^+ to enter the cell. A corresponding decrease in action potential amplitude, duration and area follows, leading to a more rapid onset depolarization, producing a faster MFCV. The more rapid action potential delivery to the muscle fibers will lead to a greater Ca^{2+} release from the sarcoplasmic reticulum, leading to faster rate of cross-bridge cycling (Gray et al., 2005, p. 379).

Davies and Young (1983) found that an increase of 3.1°C in muscle temperature was associated with a decrease in time to peak tension and half-relaxation time. Reducing muscle temperature by 8.4°C had the opposite effect on muscle contractile properties. In a related study (Davies, Mecrow, & White, 1982), similar results were found as exercise and heating decreased time to peak tension and half-relaxation time, while cooling had the opposite effect of prolonging them. Cooling additionally reduced supramaximal twitch tension, while heating had no effect. MVC was also reduced due to cooling. Given the complexity and speed of a pitching movement, temperature elevation enhancement of neural transmission, MFCV, and MVC could benefit pitching by allowing sarcomeres to more rapidly activate leading ultimately to increased muscle contractile speed.

In an applied study of elite soccer players, it was found that a decline in core and muscle temperature during a 15 min halftime decreased 30-meter sprinting capacity by 2.4% at the beginning of the second half for the control group who recovered passively. However, sprint speed was maintained by subjects who rested for the first seven minutes of halftime and then performed seven minutes of running and other exercises at an average heart rate of about 135 beats/min or about 70% of the peak heart rate reached during the first half. The WM exercises were completed with one minute left before the start of the second half and muscle temperature, measured in the medial aspect of the vastus lateralis by a needle thermistor, was about 1.5°C higher in the WM group compared to the control group. Sprint performance was reduced by 1.2% per degree Celsius drop in muscle temperature after halftime across both groups. The authors concluded that muscle and core temperature decrease noticeably while recovering passively during a 15 min half-time break and that lower temperatures were associated with significant impairment in sprint performance. The researchers suggested that high muscle temperature is important for performances, such as repeated sprints (Mohr, Krustrub, Nybo, Nielsen, & Bangsbo, 2004).

Oxygen Delivery

Warm-up is thought to increase performance by increasing muscle oxygen delivery due to vasodilation and increased blood flow, as well as through an acidemia-induced rightward shift in the oxyhemoglobin dissociation curve, which would improve O_2 diffusion between the capillary blood and mitochondria (Gerbino, Ward, & Whipp, 1996). Almost twice as much oxygen dissociates from hemoglobin at 41°C compared to 36°C (Barcroft & King, 1909). It is believed that warm-up may allow tasks to begin with an elevated baseline VO_2, resulting in lower O_2 deficit and maintaining high-energy phosphate levels. Additionally, higher temperatures stimulate vasodilation of blood vessels and increase muscle blood flow (Barcroft & Edholm, 1943). Therefore, an increase in temperature should increase oxygen delivery to the muscles, however this would benefit activities limited by VO_2 kinetics which most likely pitching is not. Although pitching is unique with cyclic motions and long durations of repeated anaerobic efforts during an inning, it should not be thought of as an O_2 limited activity. Despite the purely anaerobic nature of a single pitch, the act of pitching an entire inning may potentially be classified as a very low-intensity “aerobic” activity. In a study of extended play (5-6 innings) on professional baseball players, an average drop in ball velocity of 2m/s (5mph) was found (Murray, Cook, Werner, Schlegel, & Hawkins, 2001). However, rest between pitches and innings should be adequate for recovery, thus late inning fatigue is likely due to neuromuscular or mechanical mechanisms rather than metabolic. Length of an inning and rate of pitches thrown would determine the importance of energy systems used to fuel the activity.

Metabolic Reactions

While pitching is likely not limited by oxygen delivery, it may be limited by other components of metabolism, which may be enhanced by warm-up. Increasing muscle temperature was shown to increase the rate of glycogenolysis, glycolysis, and high-energy phosphate degradation during exercise (Febbraio, Carey, Snow, Stathis, & Hargreaves, 1996). Febbraio (2000) also found that submaximal exercise in a heated environment enhances intramuscular carbohydrate utilization when there is a marked (>0.5°C) increase in body core temperature. Accordingly, exercise in heat also increases circulating epinephrine approximately two-fold, increasing muscle glycogenolysis (Febbraio, 2000). Fink, Costill, and Van Handel (1975) also found an enhanced rate of glycolysis, as indicated by increased lactate production and intramuscular glycogen utilization, during 15 min cycling bouts in a hot (41°C) environment.

In three very similar studies (Ball, Burrows, & Sargeant, 1999; Lacerda et al., 2007; Linnane, Bracken, Brooks, Cox, & Ball, 2004) of two 30 s cycle sprints in varying environmental temperatures, similar results were found. Environmental chamber temperatures ranged from 18.7°C-35°C (and a 43°C water bath) and in all three studies peak power output was observed when cycling in higher temperatures compared to a more neutral environment. Mean power output was also higher in the warm conditions, however a faster rate of fatigue and greater decrease in mean power output between sprint one and sprint two was common in warmer environments. Two of the studies found elevated plasma ammonia levels after the warm trials, indicating a possible increase in adenine nucleotide loss, resulting in an increased cross-bridge cycling rate and high-energy phosphate turnover in warm conditions. Ultimately, warm conditions resulted in a 25% increase in peak power output, a 15% increase in mean power output, and a 1°C increase in core body temperature, potentially leading to improved performance.

Despite increases in anaerobic metabolism, rapid breakdown of glycogen and increase onset of fatigue could potentially hinder prolonged performances, however increased metabolism could potentially improve short-duration performances. Given pitching's pattern of activity, which involves rest (between pitches and innings), increased anaerobic metabolism could prove to be beneficial.

Blood Flow

Warming-up increases blood flow to the active muscles, which is believed to help speed VO_2 kinetics, although this has not yet been conclusively demonstrated (Bishop, 2003). A study of two maximal 30 s cycle sprints with four minutes of active recovery at 40% VO_{2max} resulted in significantly higher mean power output during the second sprint compared to the second sprint after passive recovery. The improvement was due to a 3.1% greater power generation during the initial 10s of the second sprint. Similar to other studies, peak plasma ammonia was significantly higher with active recovery. The authors suggested:

> Higher heart rate during the active recovery together with the similar mean blood pressure and blood volume during active and passive recovery would suggest that blood flow to the legs was greater during active recovery and, thus, total peripheral resistance was greater during passive recovery (Bogdainis, Nevill, Lakomy, Graham & Louis, 1996, p. 467).

Increased blood flow to the legs is believed to enhance phosphocreatine resynthesis and/or allow a faster glycolytic rate by removing H^+ (Bogdainis et al.).

Interestingly, a preliminary research study on upper extremity blood flow in collegiate and high school baseball pitchers during a simulated game found that pitching arm blood flow increased steadily through the first 40 pitches (Bast, Perry, Poppiti, Vangsness, & Weaver, 1996). However, blood flow began to decline from pitches 60 through 100 and continued to decline for up to one hour after pitching. Coinciding with the decrease in blood flow was a decrease in pitching velocity. The thought is that given the angles of the shoulder during baseball pitching, a partial occlusion of the subclavian and axillary arteries are very real possibilities, leading to decreased blood flow resulting in a “fatigue phenomenon” characterized by premature pitching arm fatigue, heaviness, and a sense of decreased velocity. It is also thought that a decrease in blood flow may be explained by fatigued skeletal muscle consuming less oxygen, which could result in autoregulatory lowering of arterial flow, causing the pressure-flow curve to shift downward (Bast et al.). If decreased blood flow to the pitching shoulder lowers velocity then potentially an increased or maintained blood flow may positively affect performance. Based on the extreme shoulder angles of baseball pitching which may cause blood flow occlusion, little can be done while pitching, but increasing blood flow between innings may be a real possibility. WM between innings may increase blood flow to the pitching shoulder and thus improve subsequent performance instead of suffering a continual decline in blood flow with each successive inning.

Postactivation Potentiation

Postactivation potentiation (PAP) is a non-temperature related mechanism related to warm-up that may improve performance. Muscular contraction always results in a degree of fatigue but may also result in an enhanced contractile property, known as PAP. PAP is a temporary increase in muscle contractile performance, particularly after high-intensity contractions. PAP is believed to be a result of elevated regulatory myosin light chain phosphorylation due to the increased Ca^{2+} sensitivity of actin and myosin (Sweeney, Bowman, & Stull, 1993). It is believed that fatigue and potentiation coexist simultaneously and performance of a muscle is directly related to the net balance between fatigue and potentiation (Rassier & MacIntosh, 2000). The concept behind PAP is that if a muscle can recover from the fatigue of a conditioning stimulus, while still remaining potentiated, then perhaps performance could be improved, either acutely or chronically through complex (high intensity resistance exercise followed by plyometric exercise) training. However, if performance resumes too soon after a conditioning stimulus, performance may suffer due to the incompletely recovery of fatigue.

In attempt to find the optimal net balance between fatigue and potentiation, Kilduff et al. (2007) had rugby players perform countermovement jumps and ballistic bench throws after a 3RM preload conditioning stimulus. The countermovement jumps and ballistic bench throws were performed after the conditioning stimulus at 15 s, 4, 8, 12, 16, and 20 min. Peak power output was significantly decreased at 15 s for both lower and upper body. However following 8- and 12-min recovery there were significant increases in peak power output for both the upper (5.3%) and lower body (8.0%). At 16 min the upper body also showed significant increases in peak power output. Chatzopoulos et al. (2007) also found that ten single repetitions at 90% of 1RM (heavy resistance stimulus) increased 0-10m and 0-30m sprint phases when performed five minutes before sprinting, however when performed three minutes before sprinting no improvement in sprint times were found.

In an attempt to see how PAP would affect activities involving more than one singular event, such as repeated throwing, Batista et al. (2007) had subjects perform ten unilateral knee extensions (1 every 30 s) at 60° per second in an isokinetic dynamometer. This was done to verify if PAP can progressively improve performance by potentiating each successive repetition. They found that with each unilateral knee extension peak torque was potentiated and increased 1.3 Nm from the previous knee extension. They also found that peak torque potentiation was maintained up to 12 min after the last knee extension.

Pitching, being a single, cyclic power movement, may potentially benefit from PAP. PAP has been found to increase the rate of force development and these increases in acceleration and ultimately velocity could be beneficial to activities such as jumping, kicking, or throwing (Sale, 2002). However, the effectiveness of PAP has not been entirely conclusive and may in fact by highly individualized based on a number of personal variables such as training status, training age, chronological age, genetics (muscle fiber-type composition), anthropometrics, gender, relative and absolute strength. Greater PAP may be related to stronger, resistance trained individuals, although this association is not entirely conclusive. In addition to personal variables, many other factors would need to be considered such as type of contraction, intensity, volume, rest interval between multiple sets, rest interval within the complex pair, and possible varying responses of different muscle groups (Robbins, 2005).

Docherty and Hodgson (2007) have even suggested that the conditioning stimuli that have been used to elicit PAP may in fact be having a warm-up effect of increasing muscle temperature or other mechanisms associated with warm-up. The use of PAP is intriguing but currently the risks and benefits of this tactic as a warm-up would have to be closely evaluated before being implemented for a sport movement such as pitching.

Stiffness and Warm-up

An increase in muscle temperature has been shown to decrease viscous resistance of the muscles and joints, in addition to decreasing the stiffness of contracting muscle fibers. Asmussen and Bøje (1945) suggested that decreased viscosity of warmer muscles use less energy to overcome resistance, allowing more energy to be directly used for performing external work. During periods of inactivity, muscle stiffness may occur if the number of stable bonds between actin and myosin increases. Active warm-up may work to break apart these bonds and decrease stiffness while increasing range of motion and potentially allowing an increased rate of force development and power (Bishop, 2003).

While muscle stiffness, instead of flexibility, for a power movement might seem to be potentially beneficial, there is a fair chance that most pitchers would not like the idea of pitching with a "stiff" shoulder. In fact, warm-up/practice pitches are often said to be taken to diminish stiffness. Velocity could improve with a shortened, "tight" motion but it may alter accuracy and negate any positive gain in velocity. Therefore, allowing a pitcher to avoid or lessen stiffness in between innings through the use of a warm-up should prove to be beneficial.

Pitching is not simply a shoulder movement, but instead a full-body movement using the legs, back, trunk and upper limbs. Due to this full-body involvement, stiffness of other joints is a consideration as well. A study by Green, Grenier, and McGill (2002) found that a warm-up followed by sitting on the bench during a basketball game led to increased stiffness in the lumbar spine in extension and lateral bending. Interestingly, they also reported that warm-up alone does not greatly alter spine stiffness, but bench rest increases spine stiffness. They noted that the warm-up ended with stretching exercises, allowing the participants to cool down, thereby permitting stiffness to return. The patterned cycle of pitching and bench rest may increase stiffness at the start of each inning. While it is not clear if warm-up would positively affect stiffness, it is clear that bench rest following activity increases low back stiffness. Knowing this, it seems logical to keep a pitcher lightly active between innings to minimize stiffness.

Short-Duration Performance and Warm-up

Pitching is a series of short-duration performances repeated consecutively with short periods of rest (~ 15-60 s) between each pitch (i.e., intense intermittent exercise). These repeated intervals of rest would classify a single pitch as an energetic event relying heavily on use of high-energy phosphates. A study of the physiological response to pitching found that lactate did not increase throughout the game signifying that anaerobic capacity does not limit pitching and is likely dependant on the ATP-PC energy system (Potteiger, Blessing, & Wilson, 1992). A warm-up that potentially taxes high-energy phosphates could ultimately lead to a decrease in performance. However, exercise at higher temperatures has been shown to increase muscle glycogen breakdown (Fink et al., 1975) as a response to increased epinephrine secretion, due to increased core temperature (Febbraio, 2000). An increase in glycolysis, when followed by recovery, could prove to be beneficial for short-duration performances.

Most studies have found that active warm-up will improve short-duration performance, but few report no or a negative effect on short-duration performance. In a study that reported no change in performance, the warm-up only consisted of three practice jumps before a vertical jump test (Pyke, 1968). These three jumps, although different from the act of pitching, resemble the several specific warm-up/practice pitches traditionally taken before an inning and are generally accepted as an adequate warm-up. On the other hand, a study comparing jumping performance and muscle temperature found a strong positive correlation between muscle temperature and jump height. Vertical jump heights were less in cold conditions (32°C) than in warm conditions (37°C). However, it was also reported that gain in counter jumping height (after 0.4m drop) was larger in cold conditions than warm, demonstrating that more elastic energy may be stored in cold muscles (Asmussen, Bonde-Petersen, & Jørgensen, 1976). While elastic energy may be beneficial for a pitching motion it must be considered with regard to all factors and a cold elastic muscle may not outweigh the benefits of a warm muscle. In another jumping study, deep knee bends (2.88%), static stretching (4.99%), and stationary running (7.8%) each improved vertical jumping performance compared to the control (Pacheco, 1957). A study measuring the relationship between maximal instantaneous muscle power and muscle temperature found that power of the lower limbs, decreased as muscle temperature decreased. An 8°C drop in muscle temperature produced a 27% decrease in maximal instantaneous muscle power. Maximal instantaneous muscle power was measured using a non-countermovement vertical jump on a force plate (Ferretti, Ishii, Moia, & Cerretelli, 1992). These jumping studies are of interest because although pitching is not a vertical movement, it is still an explosive anaerobic movement with a powerful hip extension drive.

When active warm-up does not improve intense power performance, the frequent theme is that a warm-up was either too easy (calisthenics or practice trials) or too intense and did not allow proper recovery (Bishop, 2003). Hawley, Williams, Hamling, and Walsh (1989) found that a pre-Wingate test warm-up (8 min) did not improve peak or mean power compared to a no warm-up condition. It was concluded that the warm-up was leading to fatigue in the untrained subjects who were unable to appropriately pace their warm-up. Given the influence an active warm-up can have on anaerobic performance, the proper intensity, duration and recovery should be considered.

Intensity, Duration, and Recovery of Warm-up

Warm-up effectiveness on short-duration performance seems to rely largely on ability to increase muscle temperature without depleting the necessary high-energy phosphates. This is based on research of muscle temperature and its effect on hand grip, cycling, and jumping by Binkhorst et al. (1977), as well as by Davies and Young (1983). Very low intensity warm-up (e.g., calisthenics) may also not sufficiently raise muscle temperature (de Vries, 1959; Pyke, 1968). Warm-up over 60% VO_{2max} results in an inverse relationship between warm-up intensity and performance and warm-ups below 62% VO_{2max} result in a 12% increase in maximal power output during a 20 s cycle ergometer test (Dolan & Sargeant, 1984). Sargeant and Dolan (1987) also found that during a 20 s cycle ergometer test prior exercise less than 60% VO_{2max} resulted in a 12% increase of maximal short-term power output. However, prior exercise greater than 60% VO_{2max} resulted in a progressive decrease in maximal short-term power output, with about a 35% decrease when prior exercise represented 100% VO_{2max}. Specifically the greatest increases in maximal peak power were observed between 33 and 48% VO_{2max} and maximal short-term power output increased 15 and 10.5% when prior exercise was 39 and 56% VO_{2max}. Bogdanis et al. (1996) also found that 4 min active recovery at 40% VO_{2max} between two 30 s maximal cycle ergometer sprints resulted in a 3.1% increase in mean power output during the initial 10 s of the second sprint, when compared to a passive recovery between sprints. It would appear that warm-up of 40-60% VO_{2max}, followed by no cooling recovery, increases temperature sufficiently while also maintaining performance levels (Bishop, 2003).

A study by Mohr et al. (2004) found that after a 7 min WM at about 70% of peak heart rate during the first half of a game, 30 m sprint performance was maintained going into the second half, compared to the passive recovery group, whose sprint times decreased by 2.4%. Based off the average heart rate of 140 bpm and peak heart rate of 147 bpm during seven innings of simulated pitching (Potteiger et al., 1992), 70% would represent about 98-103 bpm. Given the age of most collegiate pitchers, 100 bpm would also represent about 50% of age predicted maximum heart rate (220-age) and would seem logical based upon the percentage ranges from the above studies.

As for duration of warm-up (10° and 20°C environment), muscle temperature rises rapidly and surpasses rectal temperature within five minutes, before stabilizing at around 10-20 min (Saltin, Gagge, & Stolwijk, 1968). Recovery should take into consideration two factors: 1) Maximal recovery of high-energy phosphates, and 2) muscle temperature remaining elevated. Depending on intensity of activity, high-energy phosphates take about five minutes to recover and muscle temperature can be expected to significantly drop after about 15-20 min. Based on this information recovery time should be about 5-15 min. A realistic pitching warm-up might be 40-50% of VO_{2max} for about 10 min, with a five minute recovery before starting an inning.

Intermediate-Duration Performance and Warm-up

Since pitchers do not simply throw one pitch, the concept of classifying pitching as strictly a short-duration performance (≤10 s) is not entirely accurate. Pitching is a series of short-duration efforts to form a single intermediate-duration performance, to constitute an inning of work. Within a given time frame, a pitcher does not actually perform more than several minutes worth of true work. A study of the physiological response to a single baseball game of pitching found that free fatty acid levels were significantly increased throughout the course of the pitching session, proving that some sort of aerobic work is being used (Potteiger et al., 1992). Because pitching can also be considered an intermediate duration effort, the effect of warm-up on intensity, duration, and recovery of such performance is considered.

Intensity, Duration, and Recovery of Warm-up

With an intermediate duration performance there must be a balance between increasing baseline VO_2 and also making sure not to fatigue the athlete with too intense a warm-up. A middle ground must be found. Bishop, Bonetti, and Dawson (2001) found that during a 2 min maximal kayak ergometer test, a 15 min, 65% VO_{2max} warm-up produced significantly greater average power during the first 60 s, while a 55% VO_{2max}

warm-up was nearly significant. However, a warm-up at 75% VO_{2max} impaired performance. Ingjer and Stromme (1979) found that an active warm-up of 50-60% VO_{2max} resulted in significantly higher oxygen uptake, lower lactate concentration, and higher blood pH during a 4 min maximal 100% VO_{2max} treadmill run, compared to a passive warm-up where the body was heated to the same temperature. De Bruyn-Prevost and Lefebvre (1980) found that a 30% VO_{2max} warm-up significantly improved time to failure during a maximal anaerobic cycle ergometer test, compared to a 75% VO_{2max} warm-up, which decreased time to failure. Failure occurred when subjects could no longer maintain a specific pedaling cadence. Using a Cunningham and Faulkner treadmill test to measure anaerobic capacity, Stewart and Sleivert (1998) found that anaerobic performance was improved after 60 and 70% VO_{2max} warm-ups, by 10 and 13%, however an 80% VO_{2max} warm-up did improve performance, and was similar to not warming-up at all.

A moderate to heavy warm-up should only require 5-10 min to reach steady state. Anything longer than 10 min and the risk of inducing excessive metabolic acidemia that impairs performance becomes a concern. Having a pitcher perform WM at a light to moderate intensity for about 10 min should be adequate to increase blood flow and muscle temperature, and safely avoid impairing subsequent performance. For intermediate warm-up recovery the main concern would be that performance begins before VO_2 levels are allowed to return to baseline and oxygen deficit increases. Sufficient recovery should be less than five minutes (Bishop, 2003).

Psychological Effects of Warm-up

Warming-up may have a psychological effect by acting as a means to mentally prepare before competition and allow athletes to reach an appropriate level of arousal. A qualitative (interview) study by Orlick and Partington (1988) showed that a defined and regularly practiced pre-performance routine, which includes mental imagery, warming-up, positive thoughts, and focusing on successful strategy, was a unique characteristic of successful Olympians. About 99% of Olympic athletes interviewed used mental imagery as part of their preparation. In addition, attentional focus as well as the quality and control of performance imagery was found to be the most important skill related to successful performance. A warm-up may simply increase and allow time to concentrate on an upcoming task or goal. In a study of open-ended interviews with expert coaches, an emphasis was put on pre-game mental preparation. One coach was quoted as saying:

> It's a mental gear to get you back to the level you were at the last time you played. I hope that while the athletes are warming up they are going through in their minds a little bit of what they are going to do in the game (Bloom, Durand-Bush, & Salmela, 1997, p. 134).

While mental preparation through the use of imagery and attentional focus before competition may be the norm for successful athletes, sports with patterns of activity and rest have a unique challenge. When reentering a game following rest an athlete is expected to perform at the level of when they left the field. However, this is frequently not the case and there may be a psychological component to the drop-off in performance.

The decrease in performance following a given interval of time is known as warm-up decrement (WUD). As a person performs a given activity, performance should increase with each successive repetition. However after even a short rest interval performance is frequently lower when activity is resumed, compared to the repetition immediately prior to rest. This phenomenon has led to the belief that "WUD is presumed to be due to an insufficient readiness to respond that occurs when relevant support systems are not properly readjusted following a rest interval" (Anshel & Wrisberg, 1993, p. 291).

Several studies by Anshel have found similar but slightly varying results. One study involved female gymnasts performing handspring vaults and found that riding a bicycle ergometer (50% predicted maximum heart rate) eliminated WUD, compared to mental practice (imagery) or seated rest, which did not result in significant reductions in WUD. The bicycle ergometer significantly enhanced both physical and affective arousal. Interestingly, positive arousal was more highly related to performance for all three treatments compared to negative arousal (Anshel, 1985).

In a second study, Anshel and Wrisberg (1993) evaluated the reduction of WUD in relation to a tennis serve. Subjects were tested on serving accuracy, arousal (Children's Arousal Scale, CAS-A) and the resultant WUD during five conditions. The five conditions were running in place (at 50% predicted maximum heart rate), positive imagery, striking a ball with the racquet toward the ground and catching (hand-eye coordination), practice serves without a ball, and a rest (control) group. WUD was significantly decreased in all groups except the control group, however the practice serves group was significantly more accurate than all other groups. Patterns of WUD recovery were similar for running in place, imagery, and striking the ball, and by the fourth repetition after rest all groups had obtained similar accuracy performance scores. All groups, except the control, increased somatic arousal, however only practice serves and running in place returned heart rate to pre-rest levels. Practice serves, the only group which eliminated WUD, also yielded significantly greater restoration of positive cognitive arousal and somatic arousal (in addition to running) while also yielding significantly greater reduction in negative cognitive arousal then all other groups.

The third article by Anshel and Wrisberg (1988) evaluated WUD of softball batting after riding a cycle ergometer, performing relevant or irrelevant imagery, or a resting (control) group. Softball batting performance was by measured success of the hit (in fair territory), distance of the hit, and subjective ratings of swing quality by two coaches. The major finds were that the bicycle ergometer significantly increased somatic arousal and bicycle ergometer and relevant imagery significantly increased the frequency of contacts on the first pitch immediately after rest. Also, a large WUD was found for irrelevant imagery and the control group for distance of hits, and a higher frequency of 'good' and 'excellent' coach's ratings were given for ball contacts of the bicycle ergometer and relevant imagery groups.

Based on the research it appears that to best eliminate WUD a degree of warm-up and/or motor pattern specific activity (i.e., specific warm-up) is required along with varying levels of cognitive and somatic arousal. While each individually may contribute to the elimination of WUD, the sum of the three could prove superior. Currently, the traditional pitching warm-up includes only motor pattern specific activity (i.e., specific warm-up of practice pitches) and potentially cognitive arousal, depending on the individual.

Throwing Velocity and Accuracy

In a study measuring the physiological response to a single pitching outing, velocity was recorded through the use of a radar gun. Subjects were told to maintain a velocity equal to 95% or more of their maximal pitching velocity. Maximal or near maximal velocity was insisted upon in order to ensure subjects performed closely to maximum effort (Potteiger et al., 1992). A study of biomechanics of fatigued pitchers also measured velocity through the use of radar gun. Pitchers were asked to throw fastballs with full effort for pitches 1-3, 7-9, and 13-15 for a 15-pitch inning. This pattern was used to maintain a 3:2 ratio of fastballs to non-fastballs (curve, slider, change-up, etc.), which is typically used by most collegiate pitchers. Velocity and additional kinematic data were only collected for the nine fastball pitches each inning (Escamilla et al., 2007). Accuracy of pitches was not recorded in either of the two studies described above.

Several studies have evaluated the effect of overload (overweight baseballs) training or overload warm-up on velocity and accuracy. All four studies are dated and used similar instruments to measure velocity, which consisted of either electrical circuits being switched on/off or chronoscopes using light and photocells to activate timers. Litwhiler and Hamm (1973) used a target with four concentric rectangles to measure accuracy. The scale ranged from 2-5 with five being the most accurate throw. Straub (1968) used a 9'x9'x1" synthetic target which had a slow recovery rate from impact to measure accuracy which was recorded on a scaled grid. Van Huss, Albrecht, Nelson, and Hagerman (1962) used a rectangular target with scores ranging from 1-5 to measure accuracy. Brose and Hanson (1967) measured accuracy by measuring the distance from the center of a target. Final accuracy score was calculated by summing the distances from the center for each throw.

A study measuring the throwing velocity and accuracy of elite and sub-elite level cricket players used a radar gun to evaluate velocity and accuracy was measured with the use of five marked zones progressing outwards, which was placed behind the cricket stump. Each zone was about 14 cm in width (about two cricket balls) and scores were recorded by two observers who sat about three to four meters from the target. A direct hit of the stump was awarded zero points, the furthest outside zone was awarded four points, and a miss of the target was awarded 5 points. A perfect score would be a zero (Freeston, Ferdinands, & Rooney, 2007).

A study evaluating the effect of WUD on tennis serves measured the accuracy of serves by having two experimenters mark the location of where the ball landed. From the determined mark the distance in centimeters was measured to the nearest point on the perimeter of the target. A serve landing in the target was awarded a score of zero. The smaller the sum of the distances, the better the accuracy score was (Anshel & Wrisberg, 1993).

In summary, velocity and accuracy can be measured several different ways. With ease of use and access, radar guns are the norm for evaluating velocity. Measuring accuracy is a bit more complex and can vary depending on the technology available and the precision required. A test of accuracy must also be sensitive enough to show a difference between treatments if one exists. A test of accuracy cannot be too easy or too difficult or else it is possible that all subjects will do exceedingly well or exceedingly poor and no treatment effect will be observed, even if one truly does exist.

Summary

Warm-up is considered by most athletes to be absolutely critical before the start of a performance. While each athlete may have a different rationale or approach to warming-up, such as jogging, stretching, practicing movement patterns, or a combination of several approaches, they are all in fact grouped into the general category of warm-up. Despite the fact that nearly all athlete's warm-up, it may be reasonable to assume that many do not know the full reasoning behind how and why they warm-up. Athlete's may warm-up based on what they have always done in the past, with no thought given to rationale, simply going through the motions.

With minimal thought being given to pre-performance warm-up it would be no surprise that little to zero thought or action is ever given to any form of warm-up-maintenance once performance has begun. For the athlete who starts the game on the bench, or is involved in periods of rest and activity this could be problematic and detrimental to their performance since the body will begin to cool and recover during rest.

Pitching being a full body movement using a powerful leg drive and somewhat violent arm motion would likely benefit from the use of proper WM. The fact that pitching is also cyclic in nature, with seated rest during each inning would potentially lend itself well to a form of WM. For a pitcher the various mechanisms of well thought-out WM, such as increased muscle temperature, increased blood flow, decreased joint stiffness, increased nerve transmission rate, and psychological benefits, may result in maintaining levels of strength and power from the end of one inning to the start of another with little or no decrease in performance. This potential maintenance of ball velocity coupled with potential maintenance or improved accuracy would better prepare the pitcher to start each inning, and ideally keep pitchers from "getting in a jam" early in an inning.

Despite the fact that WM is not the norm at any level of baseball, there is evidence that shows a period of activity followed by rest and resumption of the same activity will result in decreased performance for several repetitions. These several repetitions or pitches could result in an unwanted lead off hit. Pitchers will take practice pitches before each inning, which may help to offset the performance decrease following rest, however the practice pitches likely do little to take advantage the benefits of warm-up mentioned above. Use of a properly planned WM, using effective warm-up protocols for activities with similar bioenergetics to pitching, could prove to be greatly beneficial compared to the current practice of sitting in the dugout while draping a coat over the throwing shoulder.

Chapter 3

METHODS

This study examines the effect of warm-maintenance on overall pitching performance. The purpose of this chapter is to present an in-depth understanding of the rationale behind how the treatment (WM) and control (NWM) conditions were designed, implemented, tested, and quantitatively evaluated. The reader should gain a clear understanding of the testing and data collection protocols. This methods section is subdivided into: (a) subjects, (b) experimental design, (c) procedures, (d) statistics, and (e) summary.

Subjects

Ithaca College varsity baseball pitchers (NCAA Division III) were recruited to participate in the study. Subjects (N = 7) were between the ages of 18 and 21 years and currently on their team's traveling roster. The Ithaca College Review Board for Human Subjects Research approved this project.

Experimental Design

After signing an informed consent form (Appendix A), subjects reported to the lab on two different occasions. On both occasions each subject pitched four simulated innings. Based on partial randomized, counter-balanced assignment, subjects pitched under both the control and treatment conditions with half pitching in the treatment condition first and half starting with the control condition. Four innings was chosen based on the average number of innings pitched (~5) by starting Ithaca College pitchers from the previous season and also based on the head coaches concern about the number of pitches that the pitchers could safely handle following the fall season. Temperature and humidity were checked and recorded before each testing session to ensure consistency.

Procedures

During a single testing session two subjects pitched, alternating back and forth in game-like fashion in order to mimic the competitive atmosphere of a game, however quantitative results of performance were not shown to the either subject. Subjects were allowed to perform their normal pre-game preparation before the start of the first inning. Pre-performance warm-up did not exceed one hour and intense activity (jogging, sprinting, biking, intense calisthenics) was not allowed 30 min prior to performance. While pitchers were allowed to perform their own individual preparation (tubing, long toss, throwing, stretching, meditating), pre-performance warm-up was carefully recorded for each subject and kept constant between each of their two pitching sessions.

As permitted during NCAA sanctioned games, eight practice pitches were taken before the first inning and five before each following inning. Subjects threw 15 pitches per inning and were cued to pitch every 25 s and rest between pitches did not exceed 30 s (Bast et al., 1996). Subjects were instructed to throw maximum, game-appropriate fastballs on pitch numbers 1-3, 7-9, and 13-15 and were asked to always maintain a velocity equal to their previously recorded maximal fastball in order to ensure that each subject was pitching at near maximal velocity. "Game-appropriate" was emphasized to the subjects as an optimal balance between both velocity and accuracy without sacrificing performance of one variable for the improvement of the other. The nine fastball pitches were of interest and measured for velocity and accuracy (Appendix B). Subjects however, were not told which pitches were being evaluated. Velocity was measured using a Jugs

Professional Sports Radar Gun (Decatur Electronics, Inc., Decatur, IL) and the calibration was checked before every half-inning. The radar gun was position behind the pitcher and aimed at home plate to record the velocity of the pitch as it crossed home plate.

Accuracy was measured with the use of a rectangular target mounted on a wall, with four specific target zones in the top-right, top-left, bottom-right, and bottom-left corners. The four corners represented primary targets within the strike zone (e.g., up and in or down and away) for successful pitching performance. Each target zone measured 5.8" x 5.8". Increments of 5.8" were chosen as it is about twice the diameter of a baseball (Freeston et al., 2007). The strike zone which contained the four target zones measured 32" x 17" (Figure 1). The width of 17" was chosen because it is the width of home plate. The target was drawn on a memory foam surface, which when contacted by the ball left a clear divot. The distance between the divot left by the pitch and the center point of a specified target zone was measured to evaluate accuracy for each pitch. To measure the distance between the pitch divot and the target a dissecting needle with a non-stretch, cloth measuring tape attached was inserted into the memory foam at the center of the divot. The measuring tape was pulled tight and the distance was then measured from the divot to the center of the specified target. Any pitch that left a mark touching the border of a target zone or within the target zone was considered to have hit the target and received a perfect score of zero.

Pitches 4-6 and 10-12 were any kind of non-fastball pitch and were not recorded for data. In a similar study of a simulated baseball pitching performance, the same pitching scheme of a 3:2 ratio of fastball to non-fastball pitches was used to reflect the

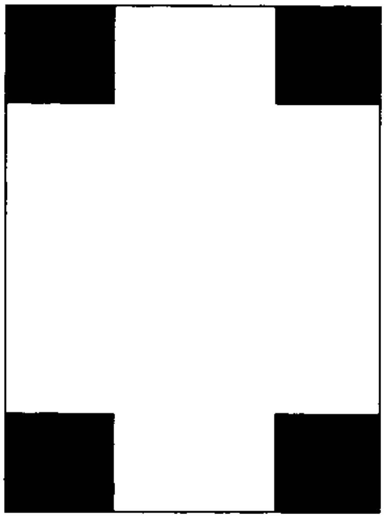


Figure 1. Diagram of target used to analyze pitching accuracy. See text for dimensional details and how the target was used for scoring pitch accuracy.

tendency of college pitchers to throw more fastballs (Escamilla et al., 2007). This pitching scheme allowed the pitches at the beginning, middle, and end of the inning to be evaluated. Since non-fastballs are intended to be slower and/or move out of the strike zone in an attempt to deceive a hitter, quantifying these pitches would prove difficult.

Pitching under the control (NWM) condition simulated the "normal" pitching pattern of performance followed by seated rest. However, a "sham treatment" was used to allow the pitchers to believe they were partaking in a different WM protocol, which could possibly improve their performance. However the workloads were short and minimal to ensure that a WM effect was not occurring. A sham treatment was used to avoid apathy from the subjects while participating in the control treatment, to ensure equal levels of effort during both conditions. After an inning of 15 pitches, the subject rested while the second subject pitched five practice pitches. The pitchers wore heart rate monitors and immediately after the opposing pitcher threw the first pitch of the inning the subject walked on the treadmill at 15% of Heart Rate Reserve (([HRmax - HRrest] x 0.15) + HRrest) for 30 sec, which was followed by 90 sec of seated rest, 30 sec of treadmill walking at 15% of Heart Rate Reserve (HRR), and then seated rest for the remainder of the inning. After sitting the remainder of the inning, 5 practice pitches were taken before throwing a 15-pitch inning. Practice pitches were taken before each inning as they are during an actual game. This pattern was continued for four 15-pitch innings.

The pitching performance under the treatment condition followed the same pattern as the control condition with subjects using their normal pre-game warm-up before the first inning but with an extra WM treatment administered before all four innings. The pitchers wore heart rate monitors and prior to the first inning the pitcher walked on a treadmill for 7.5 min at an intensity of 45% HRR (([HRmax - HRrest] x 0.45) + HRrest). Subjects were told to try and maintain HR at 45% of HRR and to never go below 40% of HRR or above 50% of HRR. This was to ensure that WM intensity never became too easy or strenuous, thus facilitating a WM effect without over fatiguing the subjects. Subjects walked on a treadmill while performing either five large forward arm circles, or five large backwards arm circles every 60 s. The direction of arm circles alternated every minute. This pattern was chosen to involve both the lower and upper musculature, which both play a role in the pitching motion, while not producing a fatiguing effect.

During innings 2-4 subjects in the WM condition sat only during the five practice pitches of the opposing pitcher before the start of each inning. During test pitches 1-15 the pitcher in the WM condition walked on the treadmill at a steady intensity to maintain a heart rate of 45% of HRR. A 15-pitch inning, with a pitch every 30 s allowed for about 7.5 min of walking between innings. The two subjects then switched after pitch number 15 and this pattern continued for four innings.

Before the start of each inning the subjects were asked to rate "How ready do you feel to pitch at this moment?" The scale was ranked from 1 to 7 with one representing "weak" and seven representing "strong" (Appendix B). This readiness scale was adapted from the Children's Arousal Scale (CAS) (Anshel, 1985). This question was asked during both treatment and control conditions.

Immediately prior to the start of each inning, for both conditions, subjects performed a shoulder range of motion (ROM) test, for both external and internal rotation. ROM was measured using a uni-level inclinometer (Isomed, Inc., Kirkland, WA) from a starting position with the humerus abducted to 90 degrees in the frontal plane and the elbow flexed to 90 degrees (Figure 2).

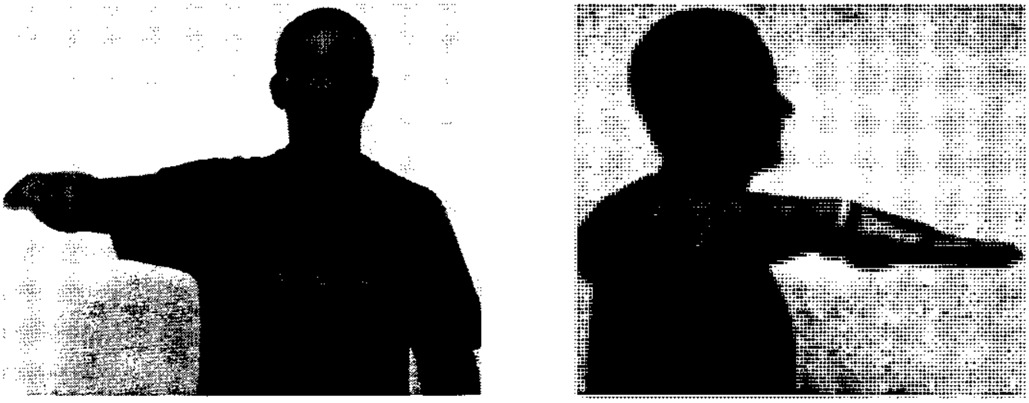
Statistics and Data Analyses

Velocity and accuracy were each analyzed using a 2x3 ANOVA (Treatment x Trial) for each inning, with repeated measures on both factors. Treatment was either WM or NWM and the trials were pitch groups 1-3, 7-9, and 13-15. For performance readiness dependant samples t-tests were used to analyze between condition effects for each inning. Pitching arm range of motion was analyzed using a 2x2 ANOVA (Treatment x Rotation) for each inning, with repeated measures on both factors. Here, treatment was either WM or NWM, while rotation was either external or internal ROM. The significance level for all statistical analyses was set at $p < 0.05$. The software package SPSS version 15 was used to analyze all data.

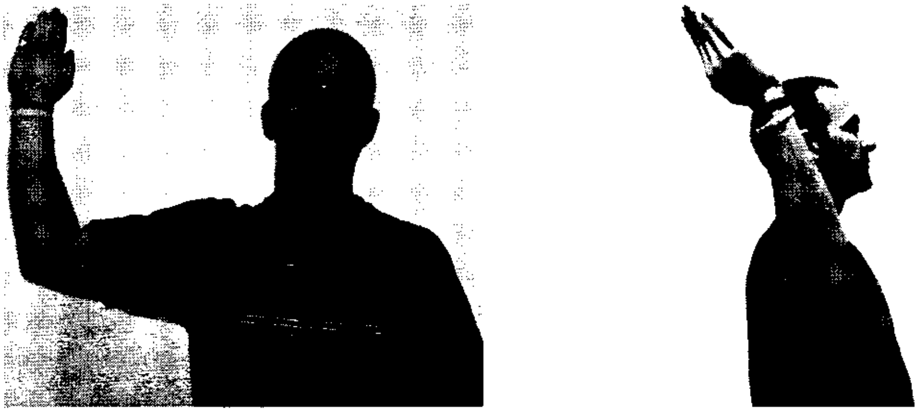
Summary

The experimental design of this study compared WM versus (NWM) conditions using repeated measures. Velocity and accuracy were chosen as the two variables necessary to interpret pitching performance. Each inning was designed to closely represent a real-life inning, with regard to number of pitches, type of pitches thrown, time between pitches, and number of innings. Accuracy was measured by distance of impact to a specified target zone and velocity was measured with the use of a radar gun. The performance readiness question was asked in an attempt to quantify a pitcher's perceived arousal and/or ability to perform optimally under the two different conditions. Shoulder ROM was measured to see if a difference arose between the two conditions. Statistics were done for all comparisons deemed important to pitching performance

Neutral (starting) Position



External Rotation



Internal Rotation

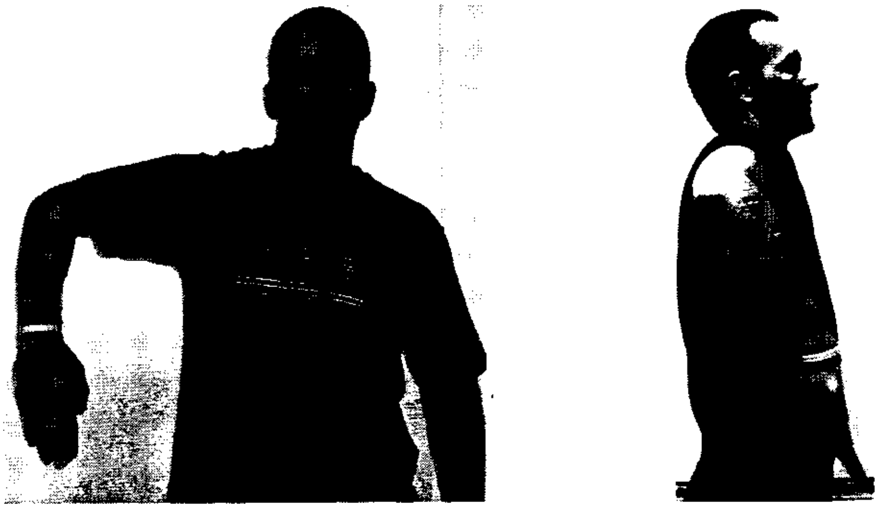


Figure 2. Photographs of arm range of motion measurement. The anatomical positioning and motions used to measure external and internal rotation.

Chapter 4

RESULTS

The purpose of this study was to determine if baseball pitchers who performed warm-maintenance (WM) by using treadmill walking and arm circles between innings maintained better ball velocity and accuracy throughout a simulated game than when using only traditional baseball warm-up pitches. Statistical analyses of data collected in this study are presented in this chapter. Raw data are found in Appendices C-I. The following sections describe results for: (a) velocity, (b) accuracy, (c) performance readiness, and (d) shoulder range of motion. Subjects (N = 7) in this study were male Ithaca College varsity baseball pitchers with a mean age of 18.8 ± 1.1 years. The average heart rates subjects were instructed to maintain were 128.1 ± 2.8 bpm during the WM condition and 93.1 ± 12.7 bpm during the no warm-maintenance (NWM) condition. All subjects completed four innings during each condition. One subject was a left-handed pitcher.

Velocity

Velocity was measured as the miles per hour of the pitch as it was crossing home plate. Sphericity was assumed for all velocity statistical analyses due to Mauchly's Test of Sphericity being greater than 0.05 for all four innings. Pitch velocity means and standard deviations for all innings and trials (groups of pitches) are illustrated in Figure 3. Mean and standard deviation values are outline in Table 1. The effects of treatment and trial on velocity were analyzed for each inning.

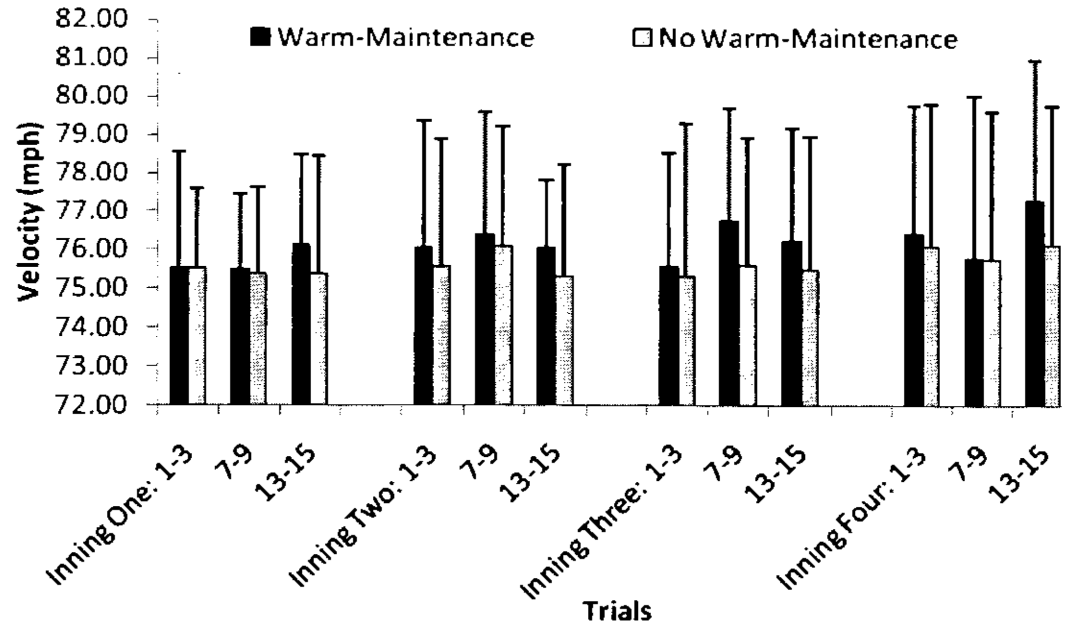


Figure 3. Means and standard deviations (error bars) for velocity. Pitch trials during the beginning, middle, and end of all four innings are represented (N = 7).

Table 1.

Velocity: Means and Standard Deviations of All Pitch Group Trials Across Innings

	WM (mph)	NWM (mph)	WM - SD	NWM - SD
Inning One				
Trials: 1-3	75.52	75.52	3.043	2.064
7-9	75.48	75.38	1.965	2.269
13-15	76.14	75.38	2.330	3.057
Inning Two				
Trials: 1-3	76.05	75.57	3.309	3.340
7-9	76.38	76.10	3.232	3.129
13-15	76.05	75.29	1.774	2.952
Inning Three				
Trials: 1-3	75.57	75.29	2.959	4.002
7-9	76.76	75.62	2.948	3.294
13-15	76.24	75.48	2.931	3.502
Inning Four				
Trials: 1-3	76.43	76.10	3.355	3.727
7-9	75.81	75.76	4.238	3.859
13-15	77.29	76.14	3.663	3.637

Note. N = 7

Inning One

To analyze velocity in inning one, a 2x3 ANOVA (Treatment x Trial) with repeated measures on both factors was used to inspect the velocity differences between the WM and NWM conditions, with respect to three groups of fastball pitches. For inning one, no significant interaction or main effects were found for velocity (Table 2).

Inning Two

To analyze velocity in inning two, a 2x3 ANOVA (Treatment x Trial) with repeated measures on both factors was used to inspect the velocity differences between the WM and NWM conditions, with respect to three groupings of fastball pitches. For inning two, no significant interaction or main effects were found for velocity (Table 3).

Inning Three

To analyze velocity in inning three, a 2x3 ANOVA (Treatment x Trial) with repeated measures on both factors was used to inspect the velocity differences between the WM and NWM conditions, with respect to three groups of fastball pitches. For inning three, no significant interaction effect was found for velocity (Table 4). There was, however, a significant trial man effect indicating a difference between pitch groups ($F_{(2,40)} = 3.497$; $p = 0.04$). Pairwise comparisons showed that there was a significant difference ($p = 0.028$) between the mean velocity for pitches 1-3 (75.43 mph) and pitches 7-9 (76.19 mph), as illustrated in Figure 4.

Inning Four

To analyze velocity in inning four, a 2x3 ANOVA (Treatment x Trial) with repeated measures on both factors was used to inspect the velocity differences between

Table 2.

Velocity: Inning One 2x3 ANOVA Summary Table

	SS	DF	MS	F	*p*
Treatment	2.57	1	2.57	0.533	0.474
Error	96.43	20	4.82		
Trial	2.48	2	1.24	0.309	0.736
Error	160.19	40	4.01		
Treatment x Trial	3.62	2	1.81	0.531	0.592
Error	136.38	40	3.41		

Note. Treatment is the analysis of WM and NWM. Trial is the analysis of pitches 1-3, 7-9, and 13-15. N = 7.

Table 3.

Velocity: Inning Two 2x3 ANOVA Summary Table

	SS	DF	MS	F	*p*
Treatment	8.13	1	8.13	1.295	0.269
Error	125.54	20	6.28		
Trial	7.43	2	3.71	1.599	0.215
Error	92.91	40	2.32		
Treatment x Trial	1.21	2	0.60	0.339	0.714
Error	71.13	40	1.78		

Note. Treatment is the analysis of WM and NWM. Trial is the analysis of pitches 1-3, 7-9, and 13-15. N = 7.

Table 4.

Velocity: Inning Three 2x3 ANOVA Summary Table

	SS	DF	MS	F	*p*
Treatment	16.79	1	16.79	2.396	0.137
Error	140.21	20	7.01		
Trial	12.25	2	6.13	3.497	0.04*
Error	70.08	40	1.75		
Treatment x Trial	3.87	2	1.94	0.481	0.622
Error	161.13	40	4.03		

Note. Treatment is the analysis of WM and NWM. Trial is the analysis of pitches 1-3, 7-9, and 13-15. *$p < 0.05$; N = 7.

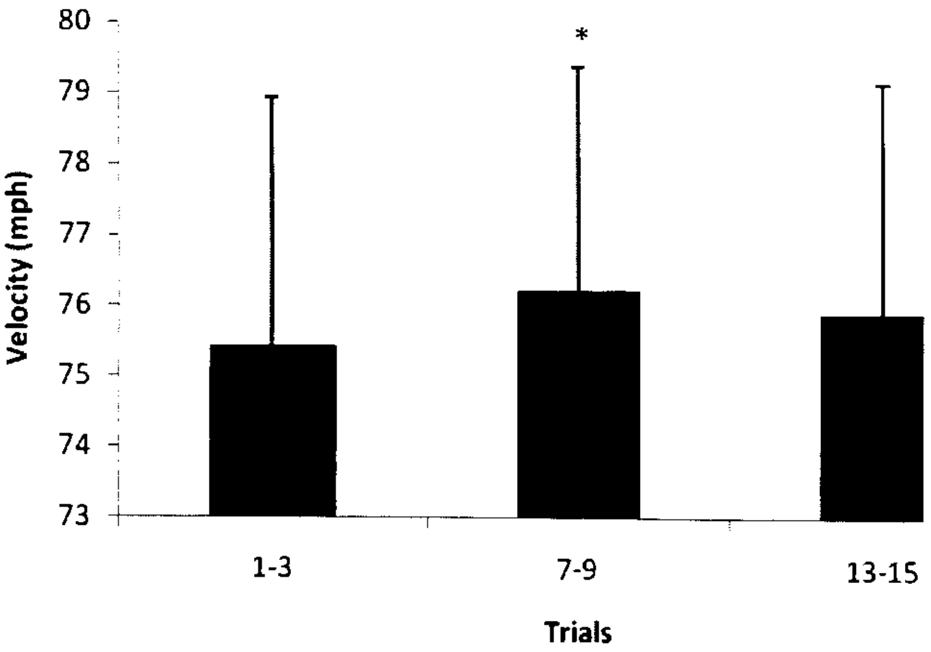


Figure 4. Inning Three - velocity means and standard deviations (error bars). Across WM and NWM groups, pitches in trials 7-9 had significantly (*$p < 0.05$) greater velocity then pitches in trials 1-3. Note. N = 7

the WM and NWM conditions, with respect to three groups of fastball pitches. For inning four, no significant interaction or main effects were found for velocity (Table 5).

Accuracy

Accuracy was measured, in millimeters, as the distance from the center of a specified target to the center of the ball divot created by pitch contact. Sphericity was assumed for all accuracy statistical analyses due to Mauchly's Test of Sphericity being greater than 0.05 for all four innings. Pitch accuracy scores greater than two standard deviations above the mean were considered outliers and removed from data analyses. Pitching accuracy means and standard deviations for all innings and trials (groups of pitches) are illustrated in Figure 5. Actual mean and standard deviation values are outlined in Table 6.

Inning One

To analyze accuracy in inning one, a 2x3 ANOVA (Treatment x Trial) with repeated measures on both factors was used to inspect the accuracy differences between the WM and NWM conditions, with respect to three groupings of fastball pitch trials. For inning one, no significant interaction or main effects were found for accuracy (Table 7).

Inning Two

To analyze accuracy in inning two, a 2x3 ANOVA (Treatment x Trial) with repeated measures on both factors was used to inspect the accuracy differences between the WM and NWM conditions, with respect to three groupings of fastball pitch trials. For inning two, no significant interaction or main effects were found for accuracy (Table 8).

Inning Three

To analyze accuracy in inning three, a 2x3 ANOVA (Treatment x Trial) with

Table 5.

Velocity: Inning Four 2x3 ANOVA Summary Table

	SS	DF	MS	F	*p*
Treatment	8.13	1	8.13	1.214	0.284
Error	133.87	20	6.69		
Trial	18.11	2	9.06	2.589	0.088
Error	139.89	40	3.50		
Treatment x Trial	6.78	2	3.39	0.648	0.529
Error	209.22	40	5.23		

Note. Treatment is the analysis of WM and NWM. Trial is the analysis of pitches 1-3, 7-9, and 13-15. N = 7.

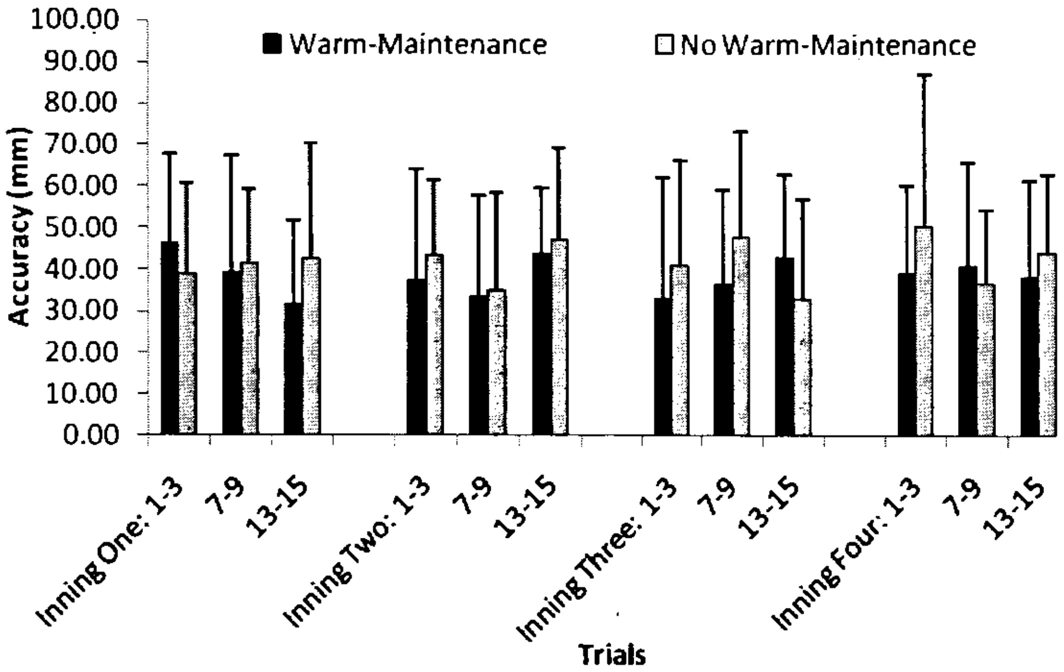


Figure 5. Pitch Accuracy - means and standard deviations (error bars) for accuracy. Pitches during the beginning, middle, and end of all four innings are represented. Lower scores indicate more accurate pitches (N = 7).

Table 6.

Accuracy: Means and Standard Deviations of All Pitch Group Trials Across Innings

	WM (mm)	NWM (mm)	WM - SD	NWM - SD
Inning One				
Trials: 1-3	46.31	38.78	21.373	21.935
7-9	39.24	41.32	28.249	17.918
13-15	31.86	42.69	19.660	27.591
Inning Two				
Trials: 1-3	37.26	43.13	26.845	18.280
7-9	33.74	35.23	23.845	23.130
13-15	43.73	46.92	15.617	22.370
Inning Three				
Trials: 1-3	33.31	41.11	28.810	25.096
7-9	36.46	47.84	22.828	25.525
13-15	43.08	33.34	19.640	23.410
Inning Four				
Trials: 1-3	39.17	50.44	20.910	36.478
7-9	40.87	37.05	25.120	17.374
13-15	38.36	43.87	22.824	19.004

Note. N = 7. A lower score indicates greater accuracy.

Table 7.

Accuracy: Inning One 2x3 ANOVA Summary Table

	SS	DF	MS	F	*p*
Treatment	101.16	1	101.16	0.127	0.725
Error	15873.83	20	793.69		
Trial	587.91	2	293.96	0.702	0.502
Error	16755.81	40	418.90		
Treatment x Trial	1770.53	2	885.26	2.058	0.141
Error	17209.98	40	430.25		

Note. Treatment is the analysis of WM and NWM. Trial is the analysis of pitches 1-3, 7-9, and 13-15. N = 7.

Table 8.

Accuracy: Inning Two 2x3 ANOVA Summary Table

	SS	DF	MS	F	*p*
Treatment	371.36	1	371.36	0.518	0.481
Error	13632.91	19	717.52		
Trial	2354.52	2	1177.26	2.000	0.149
Error	22363.56	38	588.52		
Treatment x Trial	97.76	2	48.88	0.165	0.848
Error	11248.58	38	296.02		

Note. Treatment is the analysis of WM and NWM. Trial is the analysis of pitches 1-3, 7-9, and 13-15. N = 7.

repeated measures on both factors was used to inspect the accuracy differences between the WM and NWM conditions, with respect to three groupings of fastball pitch trials. For inning three, no significant interaction or main effects were found for accuracy (Table 9).

Inning Four

To analyze accuracy in inning four, a 2x3 ANOVA (Treatment x Trial) with repeated measures on both factors was used to inspect the accuracy differences between the WM and NWM conditions, with respect to three groupings of fastball pitch trials. For inning four, no significant interaction or main effects were found for accuracy (Table 10).

Performance Readiness

Performance Readiness was measured using a 1-7 scale with one representing feeling "weak" and seven representing feeling "strong." A higher score indicated a greater feeling of readiness to pitch. Dependant samples t-tests were used to analyze between condition effects for performance readiness of each inning. For all four innings, WM had no effect on performance readiness, as seen in Table 11.

Pitching Arm Shoulder Range of Motion

Pitching arm shoulder range of motion was measured in degrees, before the start of each inning, for both external and internal rotation. Range of motion (ROM) was measured from a starting position with the humerus abducted to 90 degrees in the frontal plane and the elbow flexed to 90 degrees. Sphericity was assumed for all ROM statistical analyses due to Mauchly's Test of Sphericity being greater than 0.05 for all four innings. External and internal ROM means and standard deviations for all innings are illustrated in Figure 6 and 7.

Table 9.

Accuracy: Inning Three 2x3 ANOVA Summary Table

	SS	DF	MS	F	*p*
Treatment	297.05	1	297.05	0.491	0.492
Error	11489.48	19	604.71		
Trial	546.09	2	273.05	0.482	0.621
Error	21527.60	38	566.52		
Treatment x Trial	2557.19	2	1278.59	2.425	0.102
Error	20034.17	38	527.22		

Note. Treatment is the analysis of WM and NWM. Trial is the analysis of pitches 1-3, 7-9, and 13-15. N = 7.

Table 10.

Accuracy: Inning Four 2x3 ANOVA Summary Table

	SS	DF	MS	F	*p*
Treatment	560.30	1	560.30	1.321	0.265
Error	8060.29	19	424.23		
Trial	699.09	2	349.55	0.701	0.502
Error	18950.20	38	498.69		
Treatment x Trial	1159.90	2	579.95	0.942	0.399
Error	23401.18	38	615.82		

Note. Treatment is the analysis of WM and NWM. Trial is the analysis of pitches 1-3, 7-9, and 13-15. N = 7.

Table 11.

Performance Readiness Results

	Mean	SD	df	t	*p*
Inning 1 - WM	4.29	0.756	6	0.548	0.60
Inning 1 - NWM	4.14	0.900			
Inning 2 - WM	4.57	0.976	6	0.420	0.69
Inning 2 - NWM	4.43	0.787			
Inning 3 - WM	4.71	0.951	6	1.594	0.09
Inning 3 - NWM	4.00	0.816			
Inning 4 - WM	4.71	0.756	6	0.975	0.69
Inning 4 - NWM	4.57	0.976			

Note. Analysis used a two-tailed dependant samples t-test (N = 7). A higher score indicates a greater feeling of readiness to pitch.

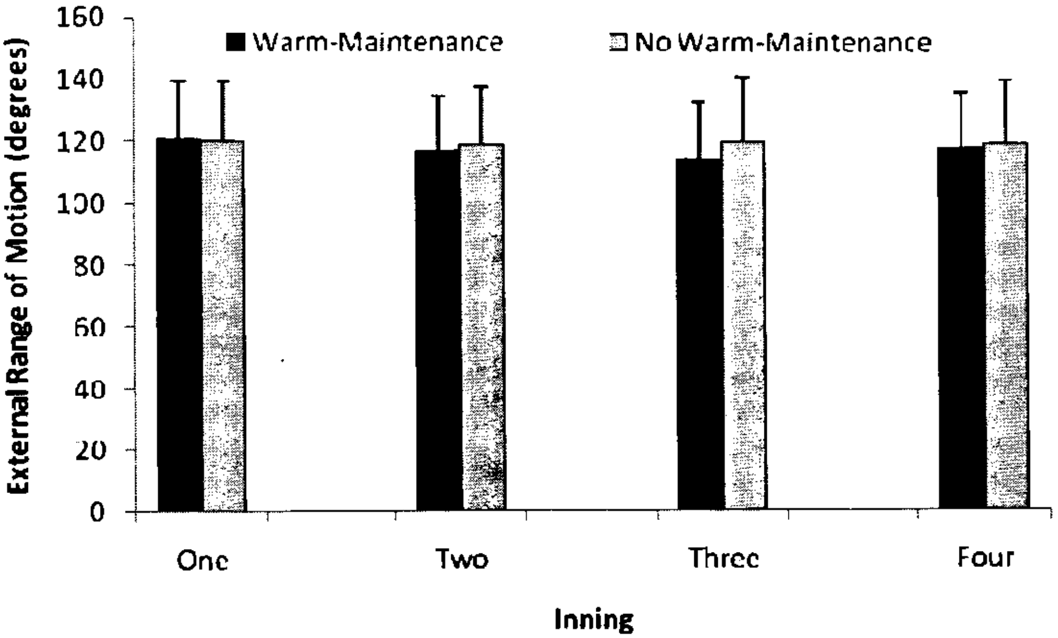


Figure 6. Pitching Arm Range of Motion – means and standard deviations (error bars) for external rotation. Range of motion was measured before the start of all four innings. Larger ranges of motion scores indicate greater degrees of external rotation (N = 7).

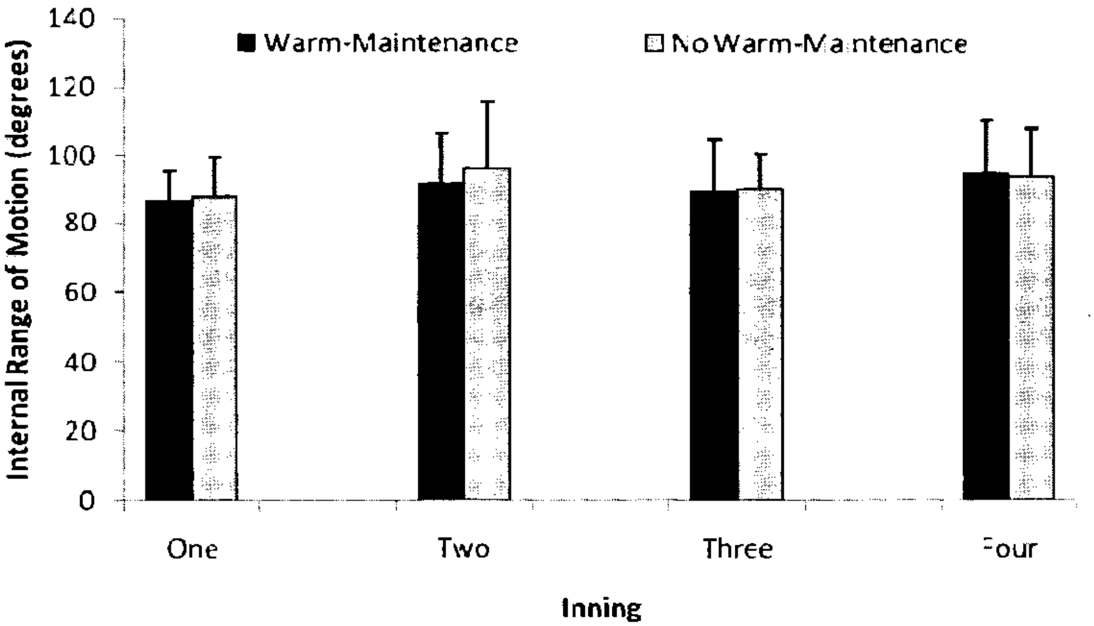


Figure 7. Pitching Arm Range of Motion – means and standard deviations (error bars) for internal rotation. Range of motion was measured before the start of all four innings. Larger ranges of motion scores indicate greater degrees of internal rotation (N = 7).

Inning One

To analyze ROM in inning one, a 2x2 ANOVA (Treatment x Rotation) with repeated measures on both factors was used to inspect the ROM differences between the WM and NWM conditions when performing internal or external rotation. For inning one, no significant interaction effect was found for ROM. A significant main effect was found for the difference between external and internal rotation regardless of condition, which was expected. No main effect was found between conditions (Table 12).

Inning Two

To analyze ROM in inning two, a 2x2 ANOVA (Treatment x Rotation) with repeated measures on both factors was used to inspect the ROM differences between the WM and NWM conditions. For inning two, no significant interaction effect was found for ROM. A significant main effect was found for the difference between external and internal rotation regardless of condition, which was expected. No main effect was found between conditions (Table 13).

Inning Three

To analyze ROM in inning three, a 2x2 ANOVA (Treatment x Rotation) with repeated measures on both factors was used to inspect the ROM differences between the WM and NWM conditions. For inning three, no significant interaction effect was found for ROM. A significant main effect was found for the difference between external and internal rotation regardless of condition, which was expected. No main effect was found between conditions (Table 14).

Table 12.

Range of Motion: Inning One 2x2 ANOVA Summary Table

	SS	DF	MS	F	*p*
Treatment	0.14	1	0.14	0.003	0.961
Error	328.86	6	54.81		
Rotation	7889.29	1	7889.29	16.932	0.006*
Error	2795.71	6	465.95		
Treatment x Rotation	7.00	1	7.00	0.193	0.676
Error	218.00	6	36.33		

Note. Treatment is the analysis of WM and NWM. Rotation is the analysis of external and internal shoulder rotation. $*p < 0.05$; N = 7.

Table 13.

Range of Motion: Inning Two 2x2 ANOVA Summary Table

	SS	DF	MS	F	*p*
Treatment	69.14	1	69.14	1.089	0.337
Error	380.86	6	63.48		
Rotation	4128.57	1	4128.57	8.123	0.029*
Error	3049.43	6	508.24		
Treatment x Rotation	14.29	1	14.29	0.488	0.511
Error	175.71	6	29.29		

Note. Treatment is the analysis of WM and NWM. Rotation is the analysis of external and internal shoulder rotation. $*p < 0.05$; N = 7.

Table 14.

Range of Motion: Inning Three 2x2 ANOVA Summary Table

	SS	DF	MS	F	*p*
Treatment	75.57	1	75.57	1.428	0.277
Error	317.43	6	52.91		
Rotation	5211.57	1	5211.57	14.153	0.009*
Error	2209.43	6	368.24		
Treatment x Rotation	41.29	1	41.29	0.626	0.459
Error	395.71	6	65.95		

Note. Treatment is the analysis of WM and NWM. Rotation is the analysis of external and internal shoulder rotation. $*p < 0.05$; N = 7.

Inning Four

To analyze ROM in inning four, a 2x2 ANOVA (Treatment x Rotation) with repeated measures on both factors was used to analyze the ROM differences between the WM and NWM conditions. For inning four, no significant interaction effect was found for ROM. A significant main effect was found for the difference between external and internal rotation regardless of condition, which was expected. No main effect was found between conditions (Table 15).

Summary

The results of these analyses indicate that although the effect of a WM between innings of pitching did not result in statistically significant improved performance indicators, there does seem to be subtle, non-significant trends toward improved performance. It is also important to note that performance never significantly declined due to the effects of WM.

For velocity, although the differences were small and not statistically significant, 11 out of 12 pitch groupings were faster during the WM condition. Similarly for accuracy, although the differences were small and not statistically significant, 9 out of 12 pitch groupings were more accurate during the WM condition. For performance readiness, WM did not seem to have an effect, although one inning did approach statistical significance. For pitching arm ROM, no statistically significant findings or trends emerged for a WM effect. External and internal ROM were significantly different in all four innings.

Table 15.

Range of Motion: Inning Four 2x2 ANOVA Summary Table

	SS	DF	MS	F	*p*
Treatment	0.57	1	0.57	0.034	0.859
Error	99.43	6	16.57		
Rotation	4032.00	1	4032.00	12.243	0.013*
Error	1976.00	6	329.33		
Treatment x Rotation	9.14	1	9.14	0.129	0.732
Error	426.86	6	71.14		

Note. Treatment is the analysis of WM and NWM. Rotation is the analysis of external and internal shoulder rotation. *$p < 0.05$; N = 7.

Chapter 5

DISCUSSION

The primary purpose of this study was to determine if baseball pitchers who performed WM, using treadmill walking and arm circles between innings, maintained better ball velocity and accuracy during a simulated game than using only a traditional warm-up of practice pitches. Additionally, this study examined if performing WM between innings affected pitching arm ROM or improved performance readiness. The primary finding of this study was that performing WM did not significantly improve pitching velocity or accuracy during the beginning, middle, or end of all four innings, compared to the NWM condition. WM also did not produce significant differences in pitching arm ROM or performance readiness.

However, there were subtle trends toward improved performance when using WM. For velocity, although the differences were small and not significant, 11 out of 12 pitch groupings, across all four innings, were slightly faster using WM. For accuracy, WM did not improve performance significantly, but 9 of 12 pitch groupings were more accurate using WM. Interestingly, the added work of doing WM between innings did not result in decreased pitching performance, but instead resulted in velocity and accuracy at least equal to NWM.

The findings of this study differ from a similar study of WM during the last 7 min of a soccer halftime (Mohr et al., 2004). It was found that sprint performance was maintained going into the second half, compared to a NWM group whose sprint performance declined by 2.4%. In the current study, performance was maintained between innings after performing WM, however NWM did not show a decline in performance.

For pitching arm ROM no significant differences emerged between WM and NWM. External and internal ROM for the pitching arm was significantly different, which is consistent with excessive external rotation during the pitching motion. For performance readiness, WM did not have a treatment effect, although inning three did approach significance.

Muscle Temperature and Warm-Maintenance Intensity

According to the National Strength and Conditioning Association, "general" warm-up of light to moderate activity increases heart rate and muscle temperature while decreasing joint viscosity (Holcomb, 2000). Warm-up has been shown to increase ATP turnover and muscle fiber conduction velocity (Gray et al., 2005), increase muscle blood flow (Barcroft & Edhholm, 1943), and improve O_2 diffusion between capillaries and mitochondria (Gerbino et al., 1996). Heating the body improves maximal muscle shortening velocity, as well as maximal power (Binkhorst et al., 1977).

By combining walking and arm circles at 45% HRR with motor pattern specific practice pitches, there was reason to believe pitching performance would improve with WM. Saltin et al. (1968) found that muscle temperature increases within five minutes of exercise, before stabilizing between 10-20 min during steady state efforts. While the current study did not measure muscle temperature, it was likely maintained or elevated by WM between innings. This temperature maintaining effect of WM may play a critical role in a colder environment when maintaining muscle temperature becomes more difficult when using only traditional practice pitches. In the present study, lab conditions were maintained near 70°F and the effects of a colder environment, though interesting, were not inspected.

Intensity of Warm-Maintenance

Choosing the correct intensity of WM is a critical issue and one that future research should further investigate. Most previous studies found that warm-up improves power performance, however Pyke (1968) reported no changes in vertical jump after three warm-up jumps. It is unlikely that three jumps elicited muscle warming and it is possible that in the current study WM was not intense enough to create a significant effect.

The WM workload in the present study fell well within the range of successful pre-activity routines from previous studies. Warm-ups below 62% (Dolan & Sargeant, 1984), less than 60% (Sargeant & Dolan, 1987), and at 40% VO_{2max} (Bogdanis et al., 1996) all found increases in power. Sargeant and Dolan found that the greatest increases in maximal peak power were observed with warm-ups between 33 and 48% VO_{2max}. Additionally, Mohr et al. (2004) found that after a WM at 70% of peak heart rate, sprint performance was maintained into the second half of a soccer game, compared to passive recovery which resulted in slower sprint times. The WM used in the present study coincided with the successful warm-up workloads used in other short-duration studies. The inability of WM at 45% HRR to produce significant improvements in this study may be related to the uniqueness of the pitching task.

With pitching being a series of short-duration efforts, collectively considered similar to an intermediate-duration performance, the proper WM intensity for such an activity needs consideration. However, there is little in the literature regarding proper warm-up intensity for these events. Significant improvements for performances lasting several minutes have been found using warm-up intensities ranging from 30% VO_{2max} (Bruyn-Prevost & Lefebvre, 1980) to 70% VO_{2max} (Stewart & Sleivert, 1998). Clearly, a middle ground must be found, which was the aim of the present study. Choosing 45% HRR was thought to adequately represent the research from both short and intermediate-duration performances studies. In previous studies when warm-up did not improve performance, the common theme was that warm-up was too easy or too intense (Bishop, 2003). In the present study, WM was controlled and performance did not decline compared to NWM. If WM were performed more intensely the impact on pitching performance remains to be seen.

Warm-up Decrement and Warm-Maintenance

Warm-up decrement (WUD) is an "insufficient readiness to respond that occurs when relevant support systems are not properly readjusted following a rest interval" (Anshel & Wrisberg, 1993). Support systems include a number of factors and WUD is attributed to psychological and physiological mechanisms. Anshel (1985) found that warm-up (50% predicted maximum heart rate) eliminated WUD of handspring vaults, compared to imagery (inactive) or seated rest, which did not reduce WUD. In the present study WUD was not detected, however, such an effect is conceivable with pitching. Throwing more than 60 pitches or pitching in cooler conditions may have elicited a WUD. If a WUD occurs than it would make a beneficial WM effect on velocity or accuracy a reasonable possibility. It is possible that five practice pitches before innings may be enough to eliminate WUD in warm conditions. Interestingly, several subjects did comment on feeling "better" or "more ready" during WM, however this did not become apparent in the performance readiness data. Anshel (1985) however did find that gymnast's physical and affective arousal were enhanced after a warm-up.

A second study by Anshel and Wrisberg (1993) found that WUD of a tennis serve was significantly decreased in all "warm-up" groups, but not for passive rest. The practice serves group was significantly more accurate than other groups. Since practice serves eliminated WUD it may prove that practice pitches are adequate for pre-inning preparation, which was illustrated in the current study. The practice tennis serves, however, were performed every 5 s for 24 repetitions, which likely had a physiological effect, and may serve as a general and specific warm-up given the quick pace and large number of repetitions. The fact that all groups in this study (Anshel & Wrisberg) decreased WUD better than imagery (inactive) and passive-rest, indicates that there may be a link between performance and WM. Additionally, the 5 min imagery group was significantly better at decreasing WUD then the 15 min imagery group, which indicates that the effect of positive imagery cannot be adequately maintained for 15 min. Too much time spent using imagery caused a physiological decline. While not directly stated, the study shows that there is a physiological component to decreasing WUD, and that a general WM, in addition to a specific WM (such as practice pitches) may be warranted for an effective WM protocol.

Innings in the present study took 7.5 min, and subjects during NWM only remained inactive for 8 min at any one time. These 8 min rest intervals might not have been long enough to elicit a WUD effect, and could be why no significant differences existed between WM and NWM. Perhaps there is a threshold beyond 8 min, where muscle cooling cannot be overcome by five practice pitches and WUD occurs. It is not unusual for a pitcher to wait 15-20 min between innings and future studies should consider the length of innings, by increasing time between pitches, or by throwing more pitches each inning.

Consideration of Limitations

Statistical Power

The major limitation of this study was that only seven subjects were tested. Originally, all Ithaca College baseball pitchers (15 subjects) were recruited but due to injury, concern about pitching volume, and personal decisions, only about half participated. While the small sample size was not ideal, the requirement for skilled baseball pitchers made recruitment of additional subjects infeasible. Given the subtle trend for improved performance with WM, the small sample size, and the high degree of accuracy variability, the consideration of statistical power is important. A post-hoc power analysis using the acquired means (±SD) of 76.1 (3.0) mph, 75.6 (3.2) mph, 38.5 (23.3) mm, and 41.5 (23.6) mm, revealed that about 470 and 750 subjects for velocity and accuracy, respectively, would need to be tested to attain significance (DSS Research, 2006). Testing such a large number of subjects to achieve significance is impractical. However, the data trends are consistent and intriguing. Future studies could aim to magnify the WM effect by altering testing conditions (e.g., colder, more pitches, more innings).

Number of Innings

Another limitation of the study was that only four innings of pitching (60 pitches) were performed, which did not allow for analysis of WM effect in late innings. Perhaps greater beneficial effects of WM would have emerged as fatigue set in. Bast et al. (1996)

found that blood flow to the throwing shoulder decreases between pitches 60 to 100, and for up to one hour after pitching. They ascribed premature arm fatigue, heaviness, decreased velocity, and the "fatigue phenomenon" to this blood flow effect. In the present study, the effects of a "fatigue phenomenon" were likely not elicited. Originally 90 pitches (six innings) were planned for this study, but excessive throwing concerns expressed by the head coach restricted the study to 60 pitches. Future research measuring throwing arm blood flow after 60 pitches is needed to see if WM prevents decreased blood flow. It may be necessary to test pitchers in-season, or immediately after the season, when their throwing arms are better conditioned and the "fatigue phenomenon" can be studied.

Applicability

One necessary limitation was testing inside the lab (70 °F) to remove uncontrollable factors, such as weather. The main rationale for examining WM is to maintain muscle temperature between innings. Testing in a warm lab might have slowed the normal decrease in muscle temperature for NWM between innings, thus partially minimizing the physiological differences between the two conditions. Greater differences in performance between WM and NWM might occur when testing in a cooler setting, as is commonly seen during an early season baseball game in the northeast USA. Future research should examine cooler settings to determine if maintaining muscle temperature through WM provides greater benefits then WM in a warm setting.

Another limitation of the study was the difficulty of simulating a competitive atmosphere in a lab, while pitching at stationary targets with no batter present. While every effort was taken to make testing as game-like as possible, the reality was that certain factors cannot be adequately simulated, such as in-game stress, fielding responsibilities, and team expectations. With no consequences or adversity, it is possible the subjects had difficulty remaining aroused for 15 pitches each inning. While this fact may impact the studies applicability, the lab simulation was equally applied across both the WM and NWM conditions.

Summary

The results of this study indicated that pitching performance does not improve with the addition of WM between innings. However, it should be noted that pitching performance did not decline with the addition of WM and did show a non-significant trend toward improvement. This study showed that WM between innings can be used effectively without a detriment to performance. By showing that velocity and accuracy can be maintained with the addition of WM, perhaps pitchers and coaches might begin to reconsider the current sedentary approach typically practiced between innings. Though not studied at this time, WM might have particular value for chilly, early season games or even during unusually long innings. While this study attempted to consider the most logical protocol, there are still a great many issues to investigate regarding WM and pitching performance.

Chapter 6

SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Summary

This study examined if pitchers who performed WM by using treadmill walking (45% HRR) and arm circles between innings maintained better ball velocity and accuracy throughout four simulated innings than when using only a traditional warm-up of seated rest and practice pitches. The effect of WM on performance readiness and pitching arm shoulder ROM was also examined. Male (N = 7) Ithaca College Baseball pitchers, aged 18-21 years, were recruited to participate in this study. Subjects reported to the lab on two different occasions. On both occasions each subject pitched four simulated innings. During a single testing session two subjects pitched, alternating back and forth to mimic the competitive atmosphere of a game. Subjects threw 15 pitches per inning and were cued to pitch every 25 s. Subjects were instructed to throw maximum, game-appropriate fastballs on pitch numbers 1-3, 7-9, and 13-15. This pitching scheme allowed the fastballs at the beginning, middle, and end of the inning to be evaluated. Accuracy was measured with the use of a rectangular target mounted on a wall, with four specific target zones. The distance between the mark left by a pitch and the center point of a specified target zone was measured to evaluate accuracy for each pitch.

Pitching under the control (NWM) condition simulated the "normal" pitching pattern of performance followed by seated rest. After an inning of 15 pitches, the subject rested while the second subject pitched. After seated rest, five practice pitches were taken before throwing a 15-pitch inning. This pattern was continued for four 15-pitch innings. The pitching performance under the treatment (WM) condition followed the same pattern as the control condition but with an extra WM treatment administered before all four innings. Prior to each inning the subject walked on a treadmill, while performing arm circles, for 7.5 min at an intensity of 45% HRR. Before the start of each inning all subjects were asked to rate their performance readiness on a scale from 1 to 7. Immediately prior to the start of each inning, all subjects performed an external and internal shoulder range of motion test.

A 2x3 ANOVA with repeated measures on both factors was used to analyze velocity (mph) for each individual inning. No significant interaction or main effects were found. A 2x3 ANOVA with repeated measures on both factors was used to analyze accuracy (mm) for each individual inning. No significant interaction or main effects were found. There was however subtle, non-significant trends for improved performance after WM. Additionally, velocity and accuracy never declined as a result of WM. Dependant samples t-tests were used to analyze performance readiness before each inning. For all four innings WM had no significant effect on performance readiness. A 2x2 ANOVA with repeated measures on both factors was used to analyze shoulder ROM for each individual inning. The only significant finding was that external rotation was greater than internal rotation, regardless of condition, which was to be expected for baseball pitchers.

The results of this study indicate that WM between innings does not improve pitching velocity, accuracy, performance readiness, or shoulder range of motion. There is however justification for future research based on the recommendations that follow.

Conclusions

Results of this study support the following conclusions:

1. Ball velocity or accuracy does not improve with the use of WM between innings when compared to the NWM condition.
2. Performance readiness scores are not improved with WM.
3. Shoulder range of motion does not differ between the WM and NWM groups.
4. WM between innings does not result in detriments to velocity, accuracy, or performance readiness.

Recommendations

After completion of this study the following recommendations for future research are of interest:

1. Testing in cooler settings to determine if maintaining muscle temperature through WM provides greater benefits than in warmer settings.
2. Determining if greater WM intensity would have a significant positive effect on pitching performance.
3. Testing with longer innings, by increasing time between pitches, or by throwing more pitches each inning, to examine if there is a certain time threshold where muscle cooling and WUD cannot be overcome by a specific warm-up of five practice pitches.
4. Measuring throwing arm blood flow, particularly after 80-100 pitches, to see if WM prevents decreased blood flow and increases performance with longer duration of pitching effort.

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Appendix A

Informed Consent Form

Effect of Warm-Maintenance Between Innings On Overall Pitching Performance

Purpose of the Study
The purpose of this study is to evaluate the effectiveness of interval and steady-state warm-maintenance between innings at maintaining ball velocity and accuracy throughout a simulated game. The effect of warm-maintenance will also be evaluated with regard to shoulder range of motion and pitching readiness.

Benefits of the Study
This study will provide knowledge that may allow improvements in performance and/or raise further questions about how performance is maintained once activity has begun. Baseball is rooted in tradition, and like many other sports and activities, warm-up is given little or no thought once activity has begun. This study could change that thought process and the actions taken to maintain the benefits of a warm-up throughout the duration of a game. This study may give you insight for physical preparation both before and during a pitching performance.

What You Will Be Asked To Do
You will be asked about your ability to participate in the study. We need to exclude you from the study if you have medical issues that prevent you from pitching or treadmill walking. After a one hour preparation you will be asked to pitch four 15-pitch innings, in addition to practice pitches taken before each inning. Two four-inning sessions of pitching will take place on two different occasions. During one session you will be asked to alternate between seated rest and light treadmill walking between each inning, while during another session you will be asked to walk on a treadmill at a steady moderate intensity and perform arm circles between innings. Your shoulder range of motion will be measured before the start of each inning and your pitching readiness will be assessed by your answer to a question. We will also assess ball velocity and accuracy on each pitch. Your total time commitment for each testing session will be about three hours.

Risks
The physical risks of this study are minimal. Physical risk will be equivalent or less than the risk of pitching during a collegiate baseball game. Your comfort level will be monitored by the primary researcher and if you feel uncomfortable, the experiment will be discontinued. You will be asked at the end of each inning if you are able to continue pitching. If an injury occurs, the researchers will provide immediate care to the best of their ability. The primary researcher has CPR/AED and Standard First Aid emergency care skills, and will communicate and act accordingly to determine if outside care is necessary. A phone in the laboratory will be used to contact Campus Safety if needed. If you feel uncomfortable at any time, the experiment can be discontinued.

Initial________

Appendix A (continued)

Compensation for Injury

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

If You Would Like More Information about the Study

Please contact the primary investigator, Ian Lockwood, to receive more information at any time about this study or to get an abstract of the results. He can be reached at (973) 534-0639 or ilockwo1@ithaca.edu. You may also contact Dr. G.A. Sforzo, faculty sponsor of the study, at sforzo@ithaca.edu.

Withdrawal from the Study

You may stop participation or withdraw from the study at any point in time without any questions or any penalty.

Confidentiality of the Data

All data acquired during the study will be kept confidential. All hard data will be kept in a locked cabinet or office file when not in use. Computer data will only refer to subjects numerical codes. Only the investigators will have access to the data. Data will be used for educational or scholarly efforts (e.g., publications, presentations, thesis), but you will be not be identified by name or any other identifying comments. If we use images that may identify you, we will get your permission to use these.

Participant's Statement

I have read the above and I understand its contents. I agree to participate in this study. I acknowledge that I am of 18 years of age or older. I have received a copy of this consent form for my own records.

____

Print Name (Participant)

____ __________________

Signature (Participant) Date

Appendix B

Data Collection Form

Condition: Treatment / Control	Subject Number:
Name:	Throws: R / L
Resting HR:	45% or 15% HRR:

Warm-up →			
Shoulder ROM		R ext	L ext
Pitching Readiness (1-7)		R int	L int
Inning 1	Location	Velocity (mph)	Accuracy (mm)
1 FASTBALL	Top Left		
2 FASTBALL	Bot Right		
3 FASTBALL	Bot Left		
4	Top Left		
5	Bot Right		
6	Bot Left		
7 FASTBALL	Top Right		
8 FASTBALL	Top Left		
9 FASTBALL	Bot Right		
10	Top Right		
11	Top Left		
12	Bot Right		
13 FASTBALL	Bot Left		
14 FASTBALL	Top Right		
15 FASTBALL	Top Left		
How feeling?		Continue?	

Appendix B (continued)

Warm-up →			
Shoulder ROM		R ext	L ext
Pitching Readiness (1-7)		R int	L int
Inning 2	Location	Velocity (mph)	Accuracy (mm)
1 FASTBALL	Bot Right		
2 FASTBALL	Bot Left		
3 FASTBALL	Top Right		
4	Bot Left		
5	Top Right		
6	Top Left		
7 FASTBALL	Top Left		
8 FASTBALL	Bot Right		
9 FASTBALL	Bot Left		
10	Bot Right		
11	Bot Left		
12	Top Right		
13 FASTBALL	Top Right		
14 FASTBALL	Top Left		
15 FASTBALL	Bot Right		
How feeling?		Continue?	

Warm-up →			
Shoulder ROM		R ext	L ext
Pitching Readiness (1-7)		R int	L int
Inning 3	Location	Velocity (mph)	Accuracy (mm)
1 FASTBALL	Bot Left		
2 FASTBALL	Top Right		
3 FASTBALL	Top Left		
4	Top Left		
5	Bot Right		
6	Bot Right		
7 FASTBALL	Bot Right		
8 FASTBALL	Bot Left		
9 FASTBALL	Top Right		
10	Top Right		
11	Top Left		
12	Bot Right		
13 FASTBALL	Top Left		
14 FASTBALL	Bot Right		
15 FASTBALL	Bot Left		
How feeling?		Continue?	

Appendix B (continued)

Warm-up →			
Shoulder ROM		R ext	L ext
Pitching Readiness (1-7)		R int	L int
Inning 4	Location	Velocity (mph)	Accuracy (mm)
1 FASTBALL	Top Right		
2 FASTBALL	Top Left		
3 FASTBALL	Bot Right		
4	Bot Left		
5	Top Right		
6	Top Left		
7 FASTBALL	Bot Left		
8 FASTBALL	Top Right		
9 FASTBALL	Top Left		
10	Bot Right		
11	Bot Left		
12	Top Right		
13 FASTBALL	Bot Right		
14 FASTBALL	Bot Left		
15 FASTBALL	Top Right		
How feeling?		Continue?	N/A

Appendix C-1

Raw Data - Velocity: Treatment Condition

Inning	Pitch Number	Subject 01	Subject 02	Subject 03	Subject 04	Subject 05	Subject 07	Subject 08
1	1	76	72	76	71	71	76	78
	2	77	76	83	71	73	76	78
	3	75	76	77	73	74	77	80
	7	74	79	76	73	73	76	79
	8	74	78	77	73	74	75	77
	9	76	76	74	73	74	77	77
	13	77	75	76	72	75	81	78
	14	76	78	76	73	74	74	76
	15	77	77	81	74	74	78	77
2	1	82	77	75	70	73	76	78
	2	78	79	76	73	71	80	76
	3	77	79	74	71	74	81	77
	7	81	79	74	71	74	78	75
	8	81	79	76	71	73	80	79
	9	79	79	74	72	74	77	78
	13	78	77	76	74	75	75	77
	14	79	77	76	73	75	78	77
	15	77	76	74	74	73	78	78
3	1	77	78	73	72	71	77	78
	2	80	79	74	73	70	75	77
	3	79	78	77	73	72	76	78
	7	79	79	73	72	73	78	78
	8	80	78	75	75	74	81	78
	9	78	78	79	72	73	81	78
	13	79	78	78	74	71	77	75
	14	80	80	77	73	73	78	78
	15	79	79	74	73	71	79	75
4	1	81	77	78	73	71	79	77
	2	81	81	74	73	72	78	77
	3	79	81	77	71	73	75	77
	7	82	80	79	73	74	64	76
	8	78	79	77	73	72	78	71
	9	80	80	76	73	72	80	75
	13	79	81	74	73	73	79	76
	14	79	80	76	73	72	83	77
	15	83	79	82	73	73	81	77

Note: All values are in miles per hour.

Appendix C-2

Raw Data – Velocity: Control Condition

Inning	Pitch Number	Subject 01	Subject 02	Subject 03	Subject 04	Subject 05	Subject 07	Subject 08
1	1	78	74	76	73	71	76	76
	2	78	73	77	74	75	78	75
	3	77	75	80	74	76	75	75
	7	77	77	78	73	73	75	75
	8	77	75	77	72	74	74	74
	9	78	76	77	72	74	81	74
	13	77	73	77	73	77	80	77
	14	79	75	79	71	73	82	74
	15	78	71	73	73	73	74	74
2	1	81	78	81	71	72	77	73
	2	78	77	78	71	71	80	73
	3	77	76	74	72	74	79	74
	7	78	77	75	73	75	79	73
	8	80	78	75	72	73	82	72
	9	79	78	78	73	74	81	73
	13	78	76	78	72	74	77	71
	14	79	78	75	72	72	79	73
	15	78	79	78	72	73	76	71
3	1	79	74	79	70	69	75	74
	2	78	76	84	71	71	79	72
	3	79	78	78	71	72	79	73
	7	81	78	78	71	71	74	78
	8	78	79	79	71	71	76	74
	9	79	79	75	71	76	76	73
	13	78	78	78	71	71	71	76
	14	78	79	77	72	71	78	77
	15	78	79	81	70	71	74	77
4	1	74	78	79	73	70	77	76
	2	77	82	78	73	71	78	75
	3	78	80	83	74	69	79	74
	7	76	79	73	72	71	80	74
	8	78	82	78	73	70	79	74
	9	79	80	80	72	70	79	72
	13	78	79	76	72	71	78	76
	14	78	81	79	71	71	81	76
	15	75	81	79	71	73	80	73

Note: All values are in miles per hour.

Appendix C-3

Raw Data – Accuracy: Treatment Condition

Inning	Pitch Number	Subject 01	Subject 02	Subject 03	Subject 04	Subject 05	Subject 07	Subject 08
1	1	63.3	70.4	49.4	46.4	90.8	83.6	68.3
	2	39.6	38.3	24.8	29.2	51.8	48.7	42.1
	3	26	53.7	42.3	41.1	45.3	0	17.5
	7	48.6	10.4	40.3	0	110.4	57.3	31.6
	8	18.1	35.9	25.3	19.8	77.9	26.1	58
	9	0	21.6	23.3	72.9	80.1	36.5	29.9
	13	24.2	57.3	11.1	25.7	19.8	0	39.8
	14	25.4	25.3	26.8	12.2	39.6	29.9	64.3
	15	20	38.4	47.5	38	85.7	15.4	22.7
2	1	32.9	24.9	28.1	16.8	48.8	33.4	0
	2	21.5	0	33.4	79.9	15.9	39.5	76.1
	3	24.4	66.6	64.9	0	68.1	69.9	89.4
	7	10.8	24	14.1	43.9	103	52.3	13.7
	8	36.7	59.2	40.2	21	32.3	0	50.8
	9	29.8	0	52.8	41.7	31.1	17.3	0
	13	41.6	58.5	66.6	33.4	70.6	39.9	21.8
	14	47.4	49.2	66.5	21.8	44.7	29.4	29.4
	15	15.3	45.2	52.4	46.5	37.4	57	35
3	1	0	40.2	49.5	50.8	44.6	18.7	19
	2	0	29.6	0	58.3	126.4	30.2	22.1
	3	39.7	15.9	0	29.3	40.7	51.1	26.4
	7	13.9	41.2	0	138.4	30.5	0	33.9
	8	48.9	18.5	45.5	17.6	42.3	20.5	51.7
	9	11.3	46.4	37.8	80.3	69.7	45.3	73.8
	13	33.8	52.9	55.1	33.7	70.7	38.6	0
	14	61.4	27	69.2	67.4	34.6	49.9	55.1
	15	40.6	69.4	24.3	20.6	37.9	19.4	66.8
4	1	35.2	0	27.7	62.1	32.5	59.3	47.8
	2	55	79.8	20.3	27.4	67.3	24.4	43.3
	3	0	41.7	55.5	40.1	21	43	33.5
	7	43.1	42.4	78.6	85.4	42.1	22.8	49.8
	8	21	32.6	50.7	17.3	88.7	40.4	14.6
	9	0	50.1	0	47.5	62	28.3	30.2
	13	20.2	44.6	16.4	77.7	98.2	27.9	55.5
	14	18.9	39.4	20	34.4	55.3	29.5	31.3
	15	24.5	30.1	74.6	17.8	29.6	21.2	0

Note: All values are in millimeters. Lower scores indicate more accurate pitches. A score of zero indicates that the pitch hit the target.

Appendix C-4

Raw Data – Accuracy: Control Condition

Inning	Pitch Number	Subject 01	Subject 02	Subject 03	Subject 04	Subject 05	Subject 07	Subject 08
1	1	27.5	19	68.1	29.9	0	79.1	71.5
	2	42.4	38.1	49.9	33.4	29.1	41.2	27.7
	3	43	17.1	0	50.9	32	38.4	76.1
	7	46.2	30.1	47.4	20.7	30	84.1	63.2
	8	16.6	33.6	29.7	39.4	42.3	61.7	23.5
	9	19.2	44.2	57.7	54.9	61.7	19.8	41.8
	13	17.7	54.2	82.9	10.7	47.5	43.5	42.4
	14	20.2	103.5	25.8	51.3	13.3	104.1	48.1
	15	40.2	21.7	27.3	56.6	11.9	55.2	18.3
2	1	30.1	33	63.7	106.3	40.3	19.3	38.4
	2	27.7	43.7	35	33.3	22.9	26.8	48.9
	3	18.1	53.9	74.4	46.3	73	76.7	57.1
	7	50.2	73.9	27.4	13.4	32.7	67.5	36.2
	8	17.2	62.4	61.7	14.7	38.5	19.6	0
	9	16.7	19.2	46.4	70	0	36.8	27.5
	13	24.2	65.6	72.6	69.6	36.9	60	74.2
	14	25.6	61.7	18.2	24.7	51.2	96.5	15.8
	15	25.5	50.1	29.4	40.2	58	38.4	34.4
3	1	35.5	51.7	30.1	23.3	49.5	24.7	93.8
	2	0	47.2	27.1	26.4	38.8	41.4	50.3
	3	55.5	17.5	109.8	43.7	37.9	17.9	25.2
	7	32.9	135	33.8	34.3	43.6	29.3	51.4
	8	16.3	46.8	71.8	45.4	35.8	22.1	52.6
	9	56.6	21.7	60.6	62.4	41.6	62.8	53.9
	13	15.9	26.9	64.4	16.7	67.4	18.6	18
	14	45.4	21.9	55.4	25.9	92.6	48.9	0
	15	29.4	36.2	41.8	0	20.7	20.6	36.6
4	1	29.5	24.5	41.7	68.7	64.6	40.6	0
	2	34.9	36.2	46.8	27.4	50.3	38.6	85.7
	3	49.2	180	23.7	52.3	121.7	78.9	35.2
	7	42.6	35.2	11.7	39	70.4	18.2	31.4
	8	22.4	57.7	51.8	53.6	65.6	26.4	52.6
	9	40.1	29.8	15.2	13.7	39.3	24.3	0
	13	69.2	34.7	74.3	44.6	58.1	0	56
	14	57.7	20.6	49.2	53.7	45.9	19.1	17.3
	15	31.8	44.9	56.9	32.1	58.9	52.4	46.4

Note: All values are in millimeters. Lower scores indicate more accurate pitches. A score of zero indicates that the pitch hit the target.

Appendix C-5

Raw Data – Performance Readiness

Treatment Condition

Inning	Subject 01	Subject 02	Subject 03	Subject 04	Subject 05	Subject 07	Subject 08
1	5	4	4	4	5	3	5
2	5	3	4	5	5	4	6
3	5	4	3	5	5	5	6
4	6	4	4	5	5	4	5

Control Condition

Inning	Subject 01	Subject 02	Subject 03	Subject 04	Subject 05	Subject 07	Subject 08
1	4	3	5	4	5	3	5
2	4	4	5	5	5	3	5
3	4	3	4	4	5	3	5
4	5	3	5	5	4	4	6

Note: All values are based off a 1-7 scale, with one representing "weak" and seven representing "strong."

Appendix C-6

Raw Data – Shoulder External Range of Motion

Treatment Condition

Inning	Subject 01	Subject 02	Subject 03	Subject 04	Subject 05	Subject 07	Subject 08
1	106	132	140	130	98	102	140
2	102	128	138	120	98	100	136
3	110	124	134	124	98	82	128
4	110	128	138	128	96	94	132

Control Condition

Inning	Subject 01	Subject 02	Subject 03	Subject 04	Subject 05	Subject 07	Subject 08
1	100	124	142	140	102	100	134
2	102	128	140	132	98	100	134
3	100	130	150	130	96	100	134
4	104	128	150	128	94	100	132

Note: All values are in degrees and are for the throwing arm only.

Appendix C-7

Raw Data – Shoulder Internal Range of Motion

Treatment Condition

Inning	Subject 01	Subject 02	Subject 03	Subject 04	Subject 05	Subject 07	Subject 08
1	98	82	90	90	78	74	94
2	108	80	102	106	82	70	94
3	108	78	108	90	80	68	94
4	108	78	122	98	88	82	90

Control Condition

Inning	Subject 01	Subject 02	Subject 03	Subject 04	Subject 05	Subject 07	Subject 08
1	108	78	80	90	98	80	80
2	112	72	94	128	102	78	88
3	102	78	96	92	102	78	84
4	108	84	100	112	94	72	90

Note: All values are in degrees and are for the throwing arm only.