Evaluating a dynamic moment of inertia bat in baseball: the influence on swing speed, training, and infrared technology

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ABSTRACT

Evaluating a dynamic moment of inertia bat in baseball: the influence on swing speed, training, and infrared technology

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Concordia University, 2021

This dissertation reports the results of multiple quantitative investigations looking at the effect of using a dynamic moment of inertia bat prototype. This dissertation includes four (4) experimental research projects. The four (4) experimental research projects look at different ways to measure the efficacy of a dynamic moment of inertia bat to improve swing speed in baseball and softball. The findings suggest that a dynamic moment of inertia bat can be used as an effective warm-up tool and an effective training tool to improve bat swing speed in competitive baseball and softball players. The findings suggest that a dynamic moment of inertia bat is superior to a weighted bat as a warm-up tool because it negates the kinesthetic illusion. When athletes combine strength training and swing training using a dynamic moment of inertia bat over a 6-week training period it can lead to a significant improvement in bat swing speed that is superior to the improvement following a normal warm-up. The last experiment confirmed that using the dynamic moment of inertia bat can replicate a high-intensity warm-up and be effective as a warm-up tool. Baseball and softball players should consider using a dynamic moment of inertia to improve their bat swing speed during their training and as an on-deck warm-up tool before their at-bat performance.

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Contribution of Authors

Tristan Castonguay, subsequently identified by the pronoun I, was the principal investigator for all experiments. The literature review and references were all created by me. I carried out the experiments for all projects in this dissertation and wrote the manuscript. For all chapters, I did the analysis. I wrote this dissertation in its entirety.

Dr. Dover was the supervisor for my master's degree. Dr. Dover helped me during all phases of my master's degree. Dr. Dover revised this document multiple times and guided me during the redaction process. Dr. Dover has helped to establish the study design for all experiments.

Dr. Mary Roberts helped with the data analysis during the motion analysis calculations of chapter 2. Her knowledge in biomechanics was very helpful to analyze the bat swing speed. Dr. Roberts's also suggested using the Kinovea software which allowed us to easily analyze our results when we used a high-speed camera.

Alcide Deschenes is the inventor of the dynamic moment of inertia bat that we used in all chapters of this dissertation. Alcide fabricated multiple dynamic moment of inertia prototypes for us to use during the experiments. All projects were supported by a MITACS grant financed by Alcide Deschesne.

Two undergraduate students were recruited to help with the logistics of the research projects. Audrée Dufresne and Marc-Antoine Bérubé were recruited to help me collect the data for experiments from chapter 2,3,4 and 5. They were recruited to assist me in the data collection but did not participate in the statistical analysis or dissertation writing.

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- Marc-Antoine Bérubé helped during the baseball experiments in chapter 2 and 3 by welcoming and guiding the baseball participants to the lab where they would get tested. Marc-Antoine Bérubé was also involved in entering the data manually in an excel file during the data collection sessions.

Table of Contents

Lists of Figures, Tables, Illustrations and Equations

Figures:

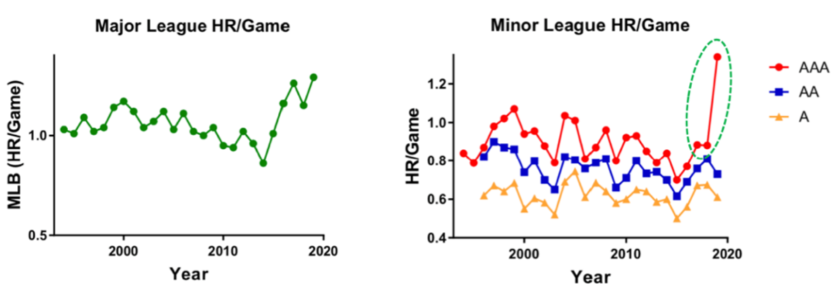
Equations:

Tables:

CHAPTER 1: GENERAL INTRODUCTION

Importance of bat swing velocity

Baseball is a very popular sport and baseball is a multi-billion-dollar industry. Some correlation exists between the entertainment value and the offensive production of the team (ex: home runs and scores). Based on the Major League Baseball, in October 2020, the team who hit more home runs won 19 games out of 20.(Petriello, 2020) Since more home runs can lead to an increase entertainment value to the viewership, teams and leagues often change the rules to give an offensive advantage. In 2011, the Nippon Professional Baseball league made changed to the balls and it led to an increase of 47% in the total number of home runs during the season. (Beals et al., 2019) The importance of the offensive production led to changes in rules, field changes and even physiological changes in players. The physiological changes were more common between 1996 and 2003 when multiple individual home runs records were broken. (Beals et al., 2019) The reason for the amazing results was later explained in the Mitchell Report. The Mitchell Report examined the use of steroids in professional baseball. In more recent years, starting after the 2015 all-star game, a significant increase in home runs has not been linked to any change in rules. (Beals et al., 2019) A home run record was broken in 2017, just to be beaten again in 2019. (Beals et al., 2019) In 2019, there was 40% more home runs compared to the 2014 season (as seen on figure 1 from Beals et Al. 2019). (Beals et al., 2019) The reason for such an increase in home runs is still undetermined. (Beals et al., 2019)



	Average (1994-2014)	Average (2004-2015)	2016	2017	2018	2019
Home Runs per Game (MLB)	1.04	1.01	1.16	1.26	1.15	1.29
Home Runs per Game (AAA)	0.91	0.87	0.77	0.91	0.88	1.34
Home Runs per Game (AA)	0.77	0.74	0.69	0.76	0.81	0.73
Home Runs per Game (A)	0.63	0.62	0.56	0.63	0.67	0.61

Figure 1. This figure was taken from Beals et Al. 2019 to illustrate the exponential increase in the number of home runs that occurred in recent years in high-level baseball. Aside from the number of home runs increasing over time, the number of home runs also increased as the level of competition increased (going from A to AAA and MLB).

Such a high increase in home runs is very impressive. It is practically impossible for baseball players to make a decision to hit or not a ball once it has been thrown. The time it leaves the hand of the pitcher and reaches the hitter, no human eye is able to pick-up the ball and adapt to its trajectory to choose how to hit the ball. For this reason, the decision that players take is more of a binary option: hit or don't hit. Once the player decides to hit; maximizing the swing speed will improve the chances of hitting the ball by increasing the reaction time and decreasing the swing time. (Hay, 1985; Polk, 1978) By waiting longer before batting, the players improve their chances of swinging accurately and hitting the sweet-spot. (Breen, 1967; DeRenne, 2007; Welch et Al., 1995) For younger players and inexperienced players, if their swing speed is slow, they will have to take a decision faster to compensate for their swing speed. (DeRenne, 2007) Once the batter started his swing, if he is able to hit the ball, the higher velocity will transfer more energy to the ball. The energy transferred to the ball will translate into a measurement called the batted-ball speed. A higher swing speed is directly related to the batted-ball speed. The higher batted-ball speed leads to a longer distance travelled by the ball. Adair determined that a lighter bat that led to a faster swing made the balls travel further. (Adair et al., 2002)

Moment of inertia

Multiple studies suggest that the moment of inertia of an implement has an inverse association with swing speed, with evidence in baseball. (Koenig et al., 2004; Schorah et Al., 2015) The definition of the moment of inertia is a measure of an object's resistance to angular acceleration about a given axis and is one of the limiting factors for maximum swing speed. (Schorah et Al., 2015) It has been shown that people are up to ten times more sensitive to differences of moment of inertia than differences in mass for objects in the range 0.3 –0.5 kg. (Kreifeldt & Chuang, 1979) In baseball, a higher moment of inertial can translate into a slower swing speed. (Hung et Al., 2004) The weight of the bats will impact the swing speed of the players because of the moment of inertia. Therefore, multiple studies have looked at lighter bats' impact on the swing speed in baseball. Since the aluminum bats are lighter, their moment of inertia is lower and can be swung faster. As it was previously mentioned, a faster swing speed leads to an increase in batted-ball speed and distance.(Fleisig et al., 2002; Laughlin et Al., 2016; Nicholls et al., 2003) A batted-ball will not travel the same distance depending on if it was batted with a wooden bat or an aluminum bat because of a difference in the weight and moment of inertia. (Adair et al., 2002; Crisco et al., 2002)

On-deck warm-up

Baseball players are used to executing a warm-up, but they are not necessarily doing it correctly or using the right tools. Completing a warm-up before participating in many different sports has been shown to improve sport performances. (Fradkin et al., 2010) A warm-up is very important because warming-up has been correlated with attaining the optimal muscle temperature required for muscle function (Mohr et al., 2004) Athletes are therefore used to warming-up before executing a sport. In Baseball, players have been using the weighted donut to warm-up on-deck before hitting for years because they feel like it is easier to swing a normal bat afterwards. (DeRenne et al., 1992; Kreifeldt & Chuang, 1979; Sergo & Boatwright, 1993) When players train or warm-up with a heavier than normal baseball bat, it has been proven to strengthen more slow-twitch muscle fibers and less fast-twitch muscle fibers.(Dabbs et Al., 2010; DeRenne et al., 1992; Otsuji et al., 2002; Reyes et Al., 2010) The higher amount of slow-twitch muscle fibers leads to a slower muscle contraction and therefore a slower swing motion. (Dabbs et Al., 2010; DeRenne et al., 1992; Otsuji et al., 2002; Reyes et Al., 2010) Multiple studies have confirmed the slower swing speed using a heavy bat and this decrease is usually around 1mph.(DeRenne et al., 1992; Otsuji et al., 2002; Reyes et Al., 2009; Southard & Groomer, 2003) Kinesthetic illusion is the term that was developed to describe the phenomenon of having a slower swing speed while feeling like it was faster.(Nakamoto et Al., 2012; Ohkoshi & Kikuchi, 1980)

Baker et al., Reyes et al. both looked and Southard et al. all looked at the impact of various bat weights of the swing speed of baseball players. The overall message to be taken out from the data collected is that a warm-up using a slightly lighter or normal bat weight will produce the highest swing speed for baseball players. Warming up with either an extremely light or heavy bats will decrease the swing speed of baseball players. (Baker et al., 2003; Reyes et Al., 2009; Southard

& Groomer, 2003) Szymanski et al. summarized the weights used in the studies previously mentioned:

Lighter bat weight	Standard bat weight	Heavy bat weight
272.2g to822.1 g	*850.5 g, or 30 oz*	*907.2-g (32-oz)*
9.6 oz to 29 oz	*893.0 g, or 31.5 oz*	*1360.8-g (48-oz)*
	963.9 g, or 34 oz	From *1190.7 to 1587.6 g*

Table 1. Various bat weights used in previous studies that examined changes in swing speed and the effects on training (Baker et al., 2003; Reyes et Al., 2009; Southard & Groomer, 2003)

Another warm-up method studied was to use multiple weights in a precise order to maximize the strength and power before hitting the ball during a game. Reyes et al. took 3 different bats of various weights (light, normal and heavy) and randomized the order of swinging each bat during warm-up. The optimal order was found to be in descending order of weight and ending with the normal bat. (Reyes et Al., 2009)

The study of the optimal rest period before hitting on-deck is also very important to be looked at because it could greatly influence the muscle fatigue and decrease performances. The rest period between pre-swing warm-up and hitting performance to maximize their swing should be between 4 to 8 minutes with a bare minimum of 2 minutes. (Wilson et Al., 2012) Waiting for 8 minutes will take advantage of the post-activation potentiation (PAP) mechanism and maximize the swing speed of baseball players. (Wilson et Al., 2012) In most studies, the rest period used was between 30 seconds and one minute because they wanted to replicate the in-game time allowed between warm-up and on-deck hitting. (Baker et al., 2003)

Biomechanics of hitting a baseball

Swinging a baseball bat and hitting a baseball requires a complex summation and transfer of forces from the ground to the trunk through the lower extremity. The trunk rotates and transfers the forces to the shoulders, elbows and wrists. The study of the biomechanics of the batting motion has been studied in detail in past studies and have isolated the timing and importance of each action sequence. Nakata et al. divided the baseball swing motion in 7 distinct phases. Phase 1 would be the waiting phase. The waiting phase is characterized by no particular movement or weight shift.

Phase 2 is the shifting body weight. The shifting body weight phase is triggered by the transfer of weight to the back-leg. Phase 3 is the stepping motion. The stepping motion is defined by the lifting of the fore foot off the ground. Phase 4 is the landing phase. The landing phase is defined by the fore foot making contact with the ground again. Phase 5 is the swing. The swing phase is initiated by the bat movement. Phase 6 is the impact. The impact is determined by the bat making contact with the ball. Phase 7 is the follow-through. The follow-through phase starts after the ball contact.(Nakata et al., 2013) The figure 2 schema included below was taken from NAKATA et Al. 2013.

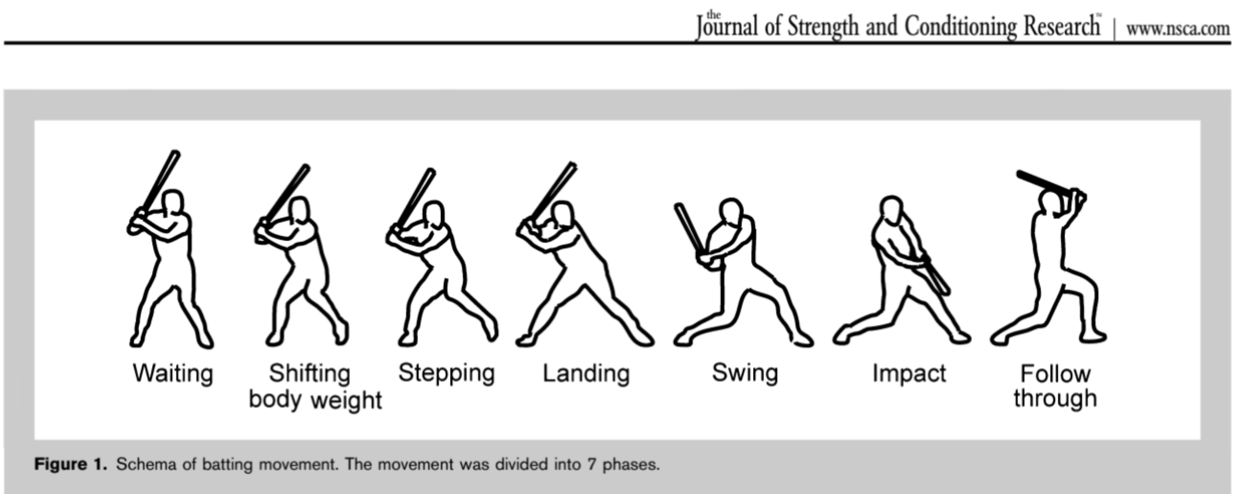


Figure 1. Schema of batting movement. The movement was divided into 7 phases.

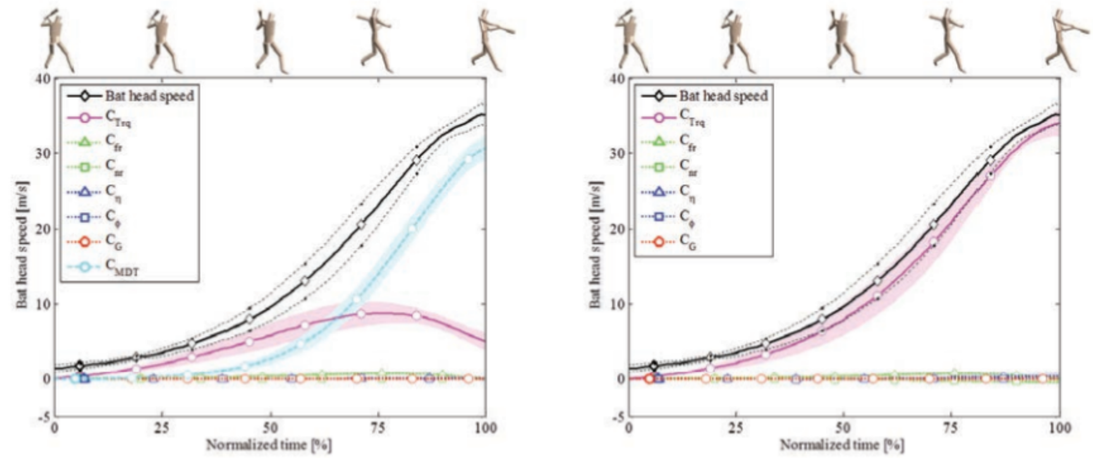
Figure 2. Koike et al. analyzed the contributors to the joint torques for the generation of bat head speed. Their main outcome was that the joint torques gradually increases until the 70%-75% relative time of swing and then gradually decreases until the completion of the swing (100% relative time). (Koike et al., 2016) In this second study, Koike et al. described in detail every torque that happens during the hitting phases. (Koike et Al., 2009)

Koike et Al. 2009 summarized results followed by the actual chart from the article that illustrates the biomechanics of a baseball swing.

- Shoulder Abduction: torque increases until 50% normalized swing motion time and stays constant until 90% swing motion time.
- Shoulder internal rotation: gradually increases until 90% swing motion.
- Torso rotation: started to increase from 60% normalized time until it reaches the maximum velocity at ball contact (100% normalized time).

- Elbow extension: started to decrease at 60% normalized time and became negative at ball impact.
- Lower limbs contributed indirectly to the bat swing speed. The results from Koike et Al. demonstrated that the function of the lower extremities was to support the upper body and control the generation of lower trunk movements. The lower limbs therefore have an effect on the trunk rotation which increases swing speed.

Sekiya Koike and Kohei Mimura / Procedia Engineering 147 (2016) 197 – 202

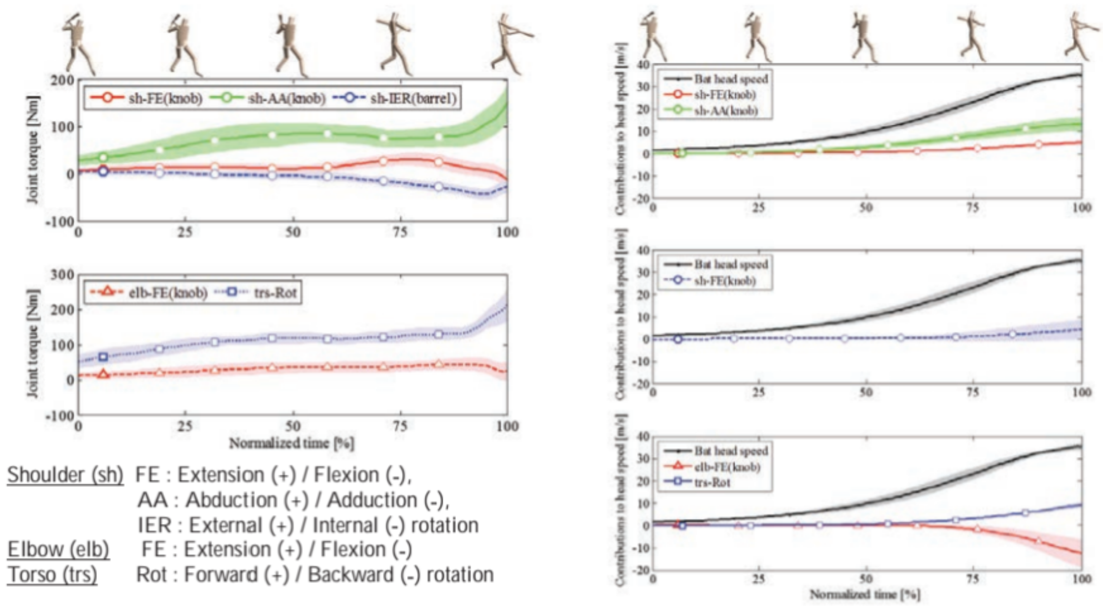


C_{Trq}: Torque term , C_{fr}: Compensational force term, C_{nr}: Compensational moment term, C_{η} : Segment length fluctuation term, C_{φ} : Constraint joint axial angle fluctuation term, C_G : Gravitational term, C_{MDT} : Motion dependent term

(a).Contributions of individual terms which contain MDT (without consideration of generating factors of MDT)

(b). Contributions of individual terms considering generating factors of MDT

Fig.2. Contributions of individual terms to bat head speed without and with consideration of generating factors of MDT.



(a). Joint torques of main contributors.

(b). Contributions of joint torques of main contributors to the bat head speed.

Figure 3. Illustrating the progression of joint torques during the 7 phases of the baseball swing, from Koike et al. 2016.

It is important to assess if a change in the bat type will affect the swing biomechanics of the players. Liu et al. were able to demonstrate that using a dynamic moment of inertia will improve the swing speed while not affecting the swing stance. (C. Liu et al., 2011) In order to swing fast, a greater amount of fast-twitch muscle fibers must be recruited. The fast-twitch muscle fibers recruitment has been proven to be possible when using a lighter bat compared to a heavy bat. (C. Liu et al., 2003)

Training programs to improve swing speed

Based on the biomechanical analysis from Nakata (Nakata et al., 2013), we can conclude that in order to improve the swing speed, a full-body approach is necessary. The importance of the whole body can be a reason why multiple training studies have focussed on a full-body approach instead of isolating specific regions. Before looking at the full-body approaches, there are some studies that looked at a potential relationship between the grip strength and the swing speed. Therefore, it has been hypothesised that training the grip strength might improve swing speed of baseball players.

Two types of trainings exist. The first type of training is the strength and conditioning. The second type of training is a swing training. Looking at the strength and conditioning, we will compare the results from general strengthening and baseball-specific swinging strengthening.

General strength training

Szymanski et al. looked at the effect on the swing speed after an 8-week medicine ball training. There was an increase in rotational power for all groups, but these improvements did not translate to the swing speed of the baseball players. It was estimated that since the participants were young, the swing speed may not be increased using a medicine ball training because they still need to improve their swing mechanic. (D. Szymanski et al., 2010) A second study, also looking at pre-pubescent softball athletes found an improvement in swing speed following an 8-week training program using medicine balls. The results were not statistically significant but the participants improved by 6.37% for the experimental group compared to a 4.55% for the control group. (Kobak et al., 2018) Grip strength training: The research regarding this topic is not unanimous. There are many studies claiming that the grip strength can improve the swing speed.(Fry et al., 2011; Spaniol et Al., 2010; Szymanski et Al., 2010) There is as much studies claiming that grip strength training cannot improve swing speed.(Albert et al., 2008; Giardina et al., 1997; Hughes et al., 2010; D. J. Szymanski et al., 2006) No clear conclusion can be drawn for the grip strength relationship to swing speed and needs to be monitored in this research project. When looking at full-body trainings' effect on bat swing velocity. The meta-analysis from Szymaski described the effect of 6 different research articles regarding strength training. The result is that 4 out of the 6 research studies have found a positive effect on swing speed after doing full-body strength and conditioning. (Szymanski et al., 2009a)

For the swing training programs, this is described as using a stick or an actual baseball bat to repetitively train the swing of the players but manipulating different variables to gradually increase the difficulty and cause an adaptation to the body. The same meta-analysis from Szymanski compared different types of swing trainings: Regular bat swinging, underweight swinging, heavy-weight training, gradual increase in resisted swings and hydro-swinging combined with supplemental resistance training. 7 studies were selected. 5 out of the 7 found a positive impact on swing speed. The 2 studies that did not provide a positive impact were the full-body training coupled with grip and forearm exercises and the hydro-swings.(Szymanski et al., 2009a)

<u>Other factors that can improve swing speed</u>

Now that we have looked at what can cause an increase in bat velocity during the baseball swing, this section is to look at other factors that can lead to an increased bat velocity and could be cofounders to our study.

Szymanski et Al. (Szymanski et Al., 2010) Looked at the relationship between the anthropometric and physiological variables on bat velocity. Their main outcome was that swing speed significantly correlated to the thickness of the abdominal wall and multifidus muscles from the dominant side. They suggested that the trunk muscles may be of higher importance for baseball swing speed rather than upper or lower limb muscles. Their results also made emphasis that the hypertrophy is more important than the difference in asymmetry from dominant side compared to non-dominant side. (Szymanski et Al., 2010) With those results, we have taken into account the importance of core and trunk muscles into our training program and focussed on hypertrophy and power.

The other very important variable to the swing speed is the skill level of the baseball players assessed. High-caliber hitters produce a higher bat swing velocities compared to low-caliber hitters. (Nakata et al., 2012) This is very important for our inclusion criteria in order to only have high-level athletes.

Thermal imaging

Since one of our baseball study is looking at the efficacy of a dynamic moment of inertia bat for warm-up, we included a novel technology in our baseline measurements to possibly assess the effect that a baseball warm-up has on the players physiologically. The technique involves the detection of infrared radiation that can be directly correlated with the temperature distribution of a defined body region. (Melnizky et al., 1997) An injury is often related with variations in blood flow and these in turn can affect the skin temperature. Inflammation leads to hyperthermia, whereas degeneration, reduced muscular activity and poor perfusion may cause a hypothermic pattern. (Garagiola & Giani, 1995) Infrared imaging has been recognized by the American Medical Association council as a feasible diagnostic tool since 1987 and was recently acknowledged by the American Academy of Medical Infrared Imaging. Various groups and associations promote the proper application of thermal imaging in the practice of sports medicine. (Hildebrandt et al., 2010) The assessment of bilateral asymmetry assumes a relevance to determine potential risks of injury and functional deficits of unhealthy athletes and non-athletes (Rodríguez-Sanz et al., 2017; Schmitt et al., 2012; Zwolski et al., 2015) as well as to quantify motor performance of healthy and athlete peers. (Bishop et al., 2018; Carabello et al., 2010; T. Liu & Jensen, 2012; Vardasca et al., 2012; Zaproudina et al., 2008) Studies from Formenti et al. (2016) and Chudecka and Lubkowska (2015) suggest that skin temperature behavior varies according to the type of exercise, intensity, duration, muscle mass and subcutaneous fat mass. (Chudecka & Lubkowska, 2012; Formenti et al., 2016) Additionally, another recent study reported significant correlation between skin temperature changes and muscle power output during an isokinetic leg extension activity on quadriceps muscle. (Hadžić et al., 2019) Likewise, Priego Quesada et al. (2017) (Quesada, 2017) found a moderate (i.e., $r = 0.5$) correlation between skin temperature and peak power output during an incremental cycling test to exhaustion on lower limb muscles. (Trecroci et al., 2018) The use of IRT has also been proposed to indirectly assess muscle damage and inflammation following exertion via skin temperature assessment. (Hildebrandt et al., 2010) It can be assumed that a continuous request of blood flow to the active muscles by incremental workloads would contribute to a continuous skin temperature reduction. However, this should be attributed not only to a decrease in skin blood flow, but may be also related to a small amount of sweat production, even it seems to have a secondary role in decreasing skin temperature (Priego Quesada et al., 2015, 2016; Trecroci et al., 2018) For our experiments, we only wanted to see how a warm-up using a dynamic moment of inertia bat would influence the skin surface temperature.

Summary

The goal of this thesis is to look at the effect of a dynamic moment of inertia in a few experiments. This unique design and way of improving swing speed has not been looked at before. Similar devices have been studied and were proven to be effective but some improvements were made in the design to possibly improve the functionality of the prototype. In our own terms, a dynamic moment of inertia bat is where the moment of inertia will vary during the swing. This is possible because the weights that are on the dynamic moment of inertia bat will gradually move towards the end of the bat as the player progresses in his swing. The weight will be close to the grip at the beginning of the swing and will move towards the end of the bat since the goal of the player is to make the weights hit the top of the bat to simulate ball contact. The further the weight is from the grip, the harder it will be to swing the bat because of the increase in the moment of inertia. We therefore looked at the effectiveness of a dynamic moment of inertia device as a warm-up tool for both competitive softball and competitive baseball players. These results will be presented in chapter 2 and chapter 3. Chapter 4 is an experiment to determine if a dynamic moment of inertia could benefit baseball athletes as a short-term training tool to improve bat swing speed over time. Chapter 5 explains the effect of warming-up with a dynamic moment of inertia but analyzed with a thermal camera to assess the change in the skin surface temperature. Together, all of these experiments are meant to explain and analyze how a dynamic moment of inertia bat influences baseball or softball performances in order to recommend or not the use of a dynamic moment of inertia bat.

CHAPTER 2: WARMING UP WITH A DYNAMIC MOMENT OF INERTIA BAT CAN INCREASE BAT SWING SPEED IN COMPETITIVE BASEBALL PLAYERS

ABSTRACT

Introduction: While most baseball players warm up with a weighted bat/donut, there is evidence to suggest the swing speed decreases even though the bat feels lighter. Warming up with a dynamic moment of inertia bat may not decrease the swing speed and therefore improve the performance of baseball players. The hypothesis is that a dynamic moment of inertia bat will negate the effect of the kinesthetic illusion observed with a weighted bat. **Objective:** To measure the difference in bat swing speed between warming-up with the dynamic moment of inertia bat compared to a weighted bat. **Methods:** Thirty-nine competitive baseball players participated in the study. All players then randomly warmed up with either the dynamic moment of inertia bat or a weighted bat and then we calculated the swing speed, therefore the players served as their own control group. The bat swing speed was measured using a high-speed camera and confirmed using inertial sensors. We used a motion analysis software to calculate the swing speed from the high-speed camera which measured the linear displacement during the last 15 frames before ball contact. **Results:** The post warm-up swing speeds using the dynamic moment of inertia bat were significantly faster compared to a weighted bat warm-up. There was a 0.56m/s ±0.78m/s (1.26mph±1.74mph) increase in swing speed when using the dynamic moment of inertia bat ($p=0.0001$) which is an average increase of 2.10% compared to a weighted bat warm-up. **Conclusions:** Our findings suggest that using a dynamic moment of inertia bat before an at-bat can increase swing speed compared to a weighted bat warm-up. Faster swing speeds can increase baseball players performance. Using a weighted bat prior to hitting may decrease swing velocity and have an adverse effect on batting.

Keywords: baseball, swing speed, dynamic moment of inertia, swing training, warm-up, kinesthetic illusion

WARMING UP WITH A DYNAMIC MOMENT OF INERTIA BAT CAN INCREASE BAT SWING SPEED IN COMPETITIVE BASEBALL PLAYERS

1. INTRODUCTION

Baseball is a popular sport, and most athletes are using a warm-up method that may not be beneficial to their bat swing speed. According to Statista and the World Baseball Softball Confederation (WBSC), there are 15 million baseball players in the United States and an estimation of 65 million worldwide. In 2016, Baseball Canada reported that 120,000 Canadians played baseball across the country and the numbers are increasing every year. Many players warm up with a weighted bat. Weighted donuts were invented in 1955 (Dickson, 1999), and provide a heavier feeling during the swing so that when the weight is removed, the bat feels lighter. However, a weighted bat has more resistance and a slower swing speed during the warm-up compared to a normal bat. (Laughlin et Al., 2016; Southard & Groomer, 2003) Furthermore, there is evidence that after warming up with a weighted bat; the resulting bat swing speed is decreased. (Montoya et Al., 2009; Nakamoto et Al., 2012; Ohkoshi & Kikuchi, 1980) The weighted device has a positive mental effect (feeling lighter) but has a negative effect on the swing speed of the normal bat; this phenomenon is called the “kinesthetic illusion”. (Otsuji et al., 2002) The kinesthetic illusion is most noticeable after warming up or preparing for an at-bat. Some authors refer to the kinesthetic illusion as the kinesthetic aftereffect. (Nakamoto et Al., 2012; Ohkoshi & Kikuchi, 1980) Many players of all levels of sport commonly use the weighted donut to warm up. A weighted donut is potentially slowing down their bat swing speed. Therefore, a better option is needed.

There is some preliminary evidence to suggest that a variable moment of inertia bat may not decrease swing speed as compared to the weighted donut (Hung et Al., 2004; C. Liu et al., 2011) and would not change the biomechanics of the player’s swing. (C. Liu et al., 2011) Moment of inertia is a measure of an object's resistance to angular acceleration about a given axis and is one of the limiting factors for maximum swing speed. (Schorah et Al., 2015) Since the mass on a baseball bat is not equally distributed along its length, the location with the most mass will require the most energy to move. (Laughlin et Al., 2016; Southard & Groomer, 2003) The mass and the location of the mass in relation to the center of rotation is called the moment of inertia. (Southard & Groomer, 2003) A direct relationship exists between the increase in bat swing speed and the decrease in bat mass.(Fleisig et al., 2002) Recently a company has created a bat which can make the weight move during a swing. If the moment of inertia bat does not negatively affect swing speed, then the prototype bat could potentially help baseball players of all levels increase their swing speed.

Bat swing speed is important and there has been more attention on bat swing speed lately in baseball. Increasing swing speed is the most common goal for being a good baseball player because of the positive relationship between batted ball speed, swing speed and distance travelled by the ball after being hit. (Szymanski et al., 2009b)-(Lyu & Smith, 2018) Swing speed is positively related to the distance travelled by the ball once batted. (Baker et al., 2003)A swing speed increase of only 1 m/s (1.6mph) can cause the hit ball to travel nearly 5m (16ft) further. (Sawicki et al., 2003) The swing speed is very important in the timing of hitting the ball because the hitter has 0.4second to decide if the player hits the ball or not once the ball is thrown. (Reyes et al., 2006) Within the 0.4s timeframe, the swing speed has to be very fast to reach the ball before missing the ball and a strike is called or to adapt to the trajectory.(Hughes et al., 2004)

Therefore, the purpose of our study was to determine if warming up with a dynamic moment of inertia bat could improve the swing speed compared to warming up with a weighted bat.

2. METHODS

2.1 Experimental Approach to the problem

Our study is a repeated measures study design. We recorded the swing speed of competitive baseball players using their regular bat, after warming up with either a dynamic moment of inertia bat or a weighted bat. The weighted bat used was actually two bats. The players would take their normal bat and take a second bat on top of it to create a heavy bat. We measured the swing speed of every athlete from our group using the same protocol described below. We then compared their results before and after they warm-up with the dynamic moment of inertia bat. Every participant swung the two types of warm-up bats in a randomized order. We received a MITACS grant (IT15640) to support the graduate student and to compensate the subjects for participating in the study. The grant money or company was not involved in any other aspect of the research.

2.2 Subjects

This study was approved by the university ethics committee (IRB #30010037) and is in accordance with the American College of Sports Medicine's policies regarding animal and human experimentation as well as the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans and with the Recommendations for the Conduct, Reporting, Editing and Publication of Scholarly Work in Medical Journals. The participants were informed of the risks and benefits of the investigation prior to signing the institutionally approved informed consent document to participate in the study. Thirty-nine subjects (age = 19.5 ± 3.3 years) were recruited from a university baseball team and from a local baseball academy. Our inclusion criteria included: all males, over 18 years old, with similar baseball experience, and no current injuries or conditions that would affect the baseball swing. All the participants were male because the baseball teams had no female players, in addition studies have indicated that female players bat swing speeds are slower which would increase the variability for the overall swing speeds. Our exclusion criteria included: players who were injured before the beginning of the study or during the study, and if the player had already been training with a dynamic moment of inertia device for some time before the start of the study.

2.3 The moment of inertia bat:

The dynamic moment of inertia bat has interchangeable weights. A picture of the dynamic moment of inertia prototype used in this study can be found in the appendices, listed as Figure 4. This bat allows the players to adjust the weight of the dynamic moment of inertia bat to weight as much as their normal bat. The ability to change the weight of the prototype allows us to avoid creating a kinesthetic illusion by having a heavier bat. The weight can move along the shaft of the bat during the swing. The dynamic moment of inertia bat forces the players to swing as fast as possible because the weight is attached to the grip by elastics. If the player doesn't swing fast enough, the weight will not move. The goal of the player is to synchronise the timing of the swing with the weight reaching the end of the bat. The weight should hit the end of the bat at the same time as the player would like to hit the ball during a swing. If for some reason the player slows his swing, the resistance bands will prevent the weight to hit the end of the bat and therefore letting know the player that his current swing was not fast enough.

The principal investigator for this research project took 10 minutes to explain to the participants how to use the prototype. Participants then had time to familiarize themselves with the prototypes during the warm-up.

2.4 Swing speed measure – High speed camera:

We used two methods to calculate swing speed to get accurate results. The first method that we used was a high-speed camera filming at 600 frames per seconds. The camera we used was the CASIO EXILIM Pro EX-F1 (Casio Computer Co., Ltd., Tokyo, Japan). The camera is positioned over their head; where we can see the distance markers on the floor, their baseball bat and ball (see figure 5). This method has been widely used in past research and will give similar results compared to a motion caption system. (Gilmore et al., 2019; P. Maletsky et al., 2007) The ICC for the analysis of angles using a high-speed video analysis with the CASIO Exilim camera was reported between 0.803 and 0.986. (Oyama et al., 2017) Based on the recommendations; the required frames per second for baseball is a minimum of 480. (Pueo, 2016) So therefore we used 600 frames per second for this study. After each swing, we transferred the video files to a computer. We used the Kinovea software (Charmant, 2019 Kinovea Version 0.8.15) for the video footage analysis. Kinovea has previously been validated as a tool to assess time-related variables. (Balsalobre-Fernández et al., 2014) The results of a past study suggest that Kinovea is a valid, precise and reliable (both inter- and intra-rater) program with which to obtain angles and distance data from coordinates. (Puig-Diví et al., 2019) The ICC for the Kinovea software is between 0.79 and 0.997. (Puig-Diví et al., 2019) Since the name of the file that has the slow-motion footage doesn't include the name of the player, all of the calculations were done by keeping that file name. This encryption allowed the researcher who was calculating the swing speed to be blinded and could not determine which group the participant was in.

We used the Kinovea software to analyze the high-speed footage, which required us to calibrate the software with distance markers on the floor and on the baseball tee to calculate the linear displacement. To be consistent, we used the last frame before the bat contacted the ball as the end of the displacement for each swing. The 15 frames that preceded the last frame were used to calculate the swing speed. This method was used in previous studies measuring bat swing speed. (Lyu & Smith, 2018; Williams et al., 2019) The Kinovea software includes a function that tracks an object's displacement. We used this function to track the 'sweet spot' on the bat. The sweet spot is 6 inches away from the end of the bat which is also consistent for what is needed to be accurate with the BLAST sensors. The total linear displacement of the sweet spot can be seen in figure 6 in the appendices. The total linear displacement of the sweet spot was determined through 15 frames, we were able to calculate the swing speed of each swing with the formula below:

$$linear\ swing\ speed\ (mph) = \frac{distance\ travelled\ by\ the\ sweet\ spot(mi)}{frame\ duration\ (h)}$$

$Equation$ 1.This equation was used to calculate the bat swing speed using the high-speed camera footage in Kinovea.

Once the swing speed was calculated for both trials for one warm-up method (either the dynamic moment of inertia bat or the weighted bat), we averaged the result. We followed the same method for the other warm-up method during the two subsequent swings.

Swing speed – inertial sensors

To confirm our speed calculations with the high-speed camera, we used the BLAST® inertial sensors. Inertial sensors are widely used because of the easiness and quickness of use. Recently, the BLAST® sensor was suggested to be the most accurate device on the market to measure swing speed in baseball. (Aguinaldo, 2016) The results of the BLAST sensor will not be presented in this study. All of the results are based on the high-speed camera calculations. When comparing the results from the motion analysis system to the BLAST® sensor, the BLAST® sensor had the lowest error margin from all of the models compared. The relative error was 5% compared to the motion capture. (Aguinaldo, 2016) The blast sensor was also used to quickly exclude bad swings when the participants were in front of the camera.

2.5 Procedures for the warm-up swinging protocol:

We welcomed every player in groups of 3 based on their position and hand dominance. The grouping of players was done to avoid having players wait for too long before doing their test after the warm-up. We measured the arm length (28.5 ± 1.1 inches). The arm length is the distance between the dominant side sternoclavicular joint and ipsilateral carpal bones. This arm length measurement was used in another study which examined the relationship between swing speed and arm length. We also used this measure to calibrate the high-speed camera footage and the

Kinovea software. We also noted the limb dominance for every player (16 lefthanded players and 23 righthanded players). After the arm length measurement, we demonstrated every player how to use the dynamic moment of inertia bat. We made sure that the prototype bat weight was equal to the player's bat weight that they will be using to swing for the analysis. We therefore weighted each bat before adjusting the weight of the prototype before giving it to the participants. We filmed two trials per warm-up bat type per player. Every player was filmed 4 times total. Every player completes the same warm-up routine: 3 swings at 75% max swing speed. To measure the bat swing after the warm-up we asked players to swing at a ball on a tee. The use of a baseball tee is common in baseball and has been used in previous swing speed analysis studies. (Dowling & Fleisig, 2016; Williams et al., 2019) While hitting from a tee has some limitations, hitting from a tee allows us to standardize some aspects of the swing to focus on the general swing mechanics. (Dowling & Fleisig, 2016) The tee is be placed one step away from the player and the height is adapted to the waist level of every player. The set-up for the swing speed analysis is shown in Figure 5. Every player has 30 seconds in-between every repetition to rest and reset their position and approximately 1 minute to change their bat type and warm-up again for the next measurements. The rest periods and time required to change warm-up methods was based on the work from Baker et Al. 2003 because they indicated that a rest duration between 30 seconds and 1 minute replicated in-game conditions. (Baker et al., 2003) (3 warm up swings – 1st recorded swing – Rest – 2nd recorded swing – new bat warm-up with 3 swings – 3rd recorded swing – Rest – 4th recorded swing). The swinging protocol is based on a previous study made by Szymasky in 2011. (D. J. Szymanski et al., 2011) The warm-ups were completed with either the prototype or the heavy bat, but every recorded swing is with their normal bat.

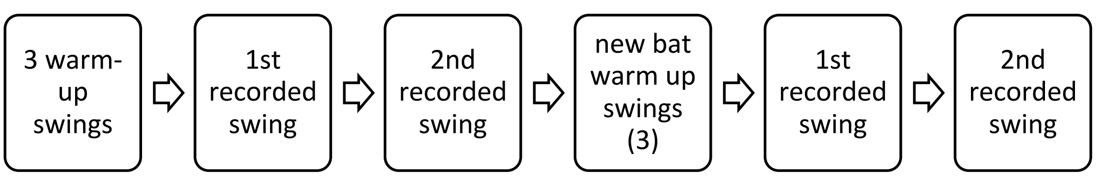


Figure 7 . Order of testing for every player.

2.6 Swinging instructions:

The participants swung at the ball on the tee as fast as if they were attempting to hit a ball from a pitcher in a game. A good quality swing for this study is that the player is able to swing as fast as possible while still hitting the ball into a catch net. An example of a “not good” swing would be if the ball is batted to the side or is only slightly touched or completely missed. A bad swing would also be in the case that the sensors or the camera didn’t record the swing. No participant had their swing excluded in our study.

2.7 Statistical Analysis:

All data were analyzed with SPSS version 26.0 (SPSS Incorporated, Chicago, IL) with a-priori alpha level for significance of $\rho \leq 0.05$. We compared both average swing speeds using a paired t-test. We estimated our power using G*Power program (v.3.1) and our sample size is similar to previous studies that have evaluated swing speeds for baseball teams with approximately 32 players.(Szymanski et al., 2009b) The statistical assumptions were respected and verified before running the statistical tests.

RESULTS

There was a significant increase in swing speed after warming up with the dynamic moment of inertia bat compared to warming up with the weighted bat. The paired t-test to test for a difference between both warm-up methods was significant ($p= 0.0001$). On average there was an improvement of 2.10% (95% confidence interval 63.5 to 66.7 mph). The average swing speed using the dynamic moment of inertia bat and the heavy bat is detailed in table 3. The results presented are calculated using the high-speed camera. Swing speeds measured with the high-speed camera of every participant are shown in table 2.

Average swing speed after warm-up with the prototype	SD	Average swing speed change after warm-up with the heavy bat	SD	Effect size (Cohens d)
29.02m/s (64.92mph)	2.23m/s (4.47mph)	28.45m/s (63.64mph)	2.40m/s (5.37mph)	0.243

Table 2. Summary table describing the average swing speed with the two different warm-up methods and the standard deviations in meters per seconds of the 39 baseball players. The effect size is also displayed.

	Prototype swing speed	Heavy swing speed			Prototype swing speed	Heavy swing speed	
#	m/s	m/s	% Change	#	m/s	m/s	% Change
1	29.17	28.25	3.24%	21	27.74	27.38	1.31%
2	24.81	25.12	-1.25%	22	25.73	25.50	0.88%
3	27.02	27.20	-0.66%	23	26.89	26.60	1.09%
4	26.82	26.35	1.78%	24	28.86	28.45	1.41%
5	28.05	27.47	2.12%	25	29.03	29.24	-0.72%
6	30.38	29.64	2.49%	26	33.28	32.79	1.50%
7	30.06	29.79	0.90%	27	29.70	29.26	1.53%
8	28.05	26.42	6.18%	28	30.59	28.89	5.90%
9	28.30	27.36	3.43%	29	30.48	29.04	4.95%
10	30.26	30.31	-0.15%	30	30.33	29.62	2.42%
11	29.48	28.21	4.52%	31	29.10	29.30	-0.69%
12	28.57	29.06	-1.69%	32	29.57	29.62	-0.15%
13	29.95	29.37	1.98%	33	27.24	25.80	5.58%
14	23.98	22.80	5.20%	34	32.25	32.45	-0.62%
15	29.62	29.73	-0.38%	35	30.17	29.62	1.89%
16	22.91	20.41	12.27%	36	30.80	29.53	4.31%
17	31.45	30.87	1.88%	37	32.14	32.48	-1.03%
18	32.28	29.57	9.15%	38	27.63	28.21	-2.06%
19	29.06	28.57	1.72%	39	30.64	29.82	2.77%
20	29.19	29.57	-1.28%				

Table 3: Summary table describing the average swing speed with the two different warm-up methods and the swing speed percentage change for the 39 baseball players.

4. DISCUSSION:

Our effect size (Cohens d) is 0.243 which is considered small (Fritz et al., 2012) but our results are still very interesting for the sport of baseball.

Increasing the swing speed is a common goal for competitive baseball players because of the positive significant relationship between batted ball speed, swing speed, and distance travelled by the ball after being hit. (Baker et al., 2003; Szymanski et al., 2009a) Swing speed is positively related to the distance travelled by the ball once batted. (Baker et al., 2003) The goal of hitting the baseball far has become the most attractive characteristic in MLB now since there is evidence that suggests hitting home runs are the most efficient way of scoring. (Goldschmied et al., 2014)

Maximizing the swing speed will improve the chances of hitting the ball by increasing the reaction time and decreasing the swing time.(Polk, 1978) By waiting longer before batting, the players improve their chances of swinging accurately and hitting the sweet-spot on the bat. (DeRenne, 2007; Welch et Al., 1995) For younger players and inexperienced players, if their swing speed is slow, they will have to take a decision faster to compensate for their swing speed. (DeRenne, 2007)

Our results suggest that using a dynamic moment of inertia bat dynamic moment of inertia bat as a warm-up tool can significantly increase bat swing speed in competitive baseball players compared to a heavy bat. The actual swing speed may not be higher than their normal bat, but it negates the negative impact of the heavier bat. Our average swing speed values are in accordance with past studies looking at athletes with a similar baseball experience. Past studies had swing speed of baseball athletes between 50mph to 80mph depending on their level of play. (Baker et al., 2003; Djuric et al., 2016; Polk, 1978; D. J. Szymanski et al., 2011) to be more precise, Welch et Al. (1995) reported average swing speeds for pro baseball players with wooden bats of 31 m/s with a standard deviation of 2 m/s (69.34 ± 4.47 mph). (Welch et Al., 1995) When we know that in baseball miles per hour translate into feet for the batted ball, even the slightest increase in swing speed can make the difference between a home run and a ball that falls short. As suggested by previous authors, even a small increase in the batted ball speed would be the difference between a ground ball out and an in-field hit, or deep fly ball compared to a home run. (Higuchi et al., 2013) In a previous study using a dynamic moment of inertia baseball bat, the participants trained with the device for a long training period. (C. Liu et al., 2011) In our study we examined immediate effect of a warm-up with a dynamic moment of inertia bat, which was able to increase bat swing speed, which differentiates us from other studies. When we compare our results, the swing speeds improved by 6.20% after a 8 week training program. (C. Liu et al., 2011) The percentage of improvement is greater than our results, but we did not allow the participants to train with the prototype. All they were allowed to do is to warm-up with the prototype. Our sample size was also bigger (N=39) compared to a previous training study (N=9 for the training group and N=8 for the control group) (C. Liu et al., 2011) Therefore, future studies are needed to determine if training with a moment of inertia bat can increase bat swing speed more.

If the players were to start warming-up with the dynamic moment of inertia bat, the players could improve their chances of hitting the ball further. When we compare the results from the swing speed using the dynamic moment of inertia bat to a heavy bat, we can clearly see that the players who use the weighted bat had poorer performances. This phenomenon has been explained using the computational theory. The computational theory states that the motor pattern is increased when the movement that occurs in the present mismatches the predicted movement. (Blakemore et al., 1999) In other words, the computation theory means that when a baseball player warms-up with a weighted bat, the player prepares himself to recreate the same action later on. The recreated action is what is referred to as a prediction. Once the player uses their normal bat, their prediction is not accurate because the bat is lighter. The players then must adjust to that new weight that creates a slower swing. Another hypothesis to explain the change in swing speed is that when we use a weighted bat to warm-up, our body is unable to control the motor inhibition that is required for movement correction. This correction leads to a different result compared to a normal bat weight. (de Azevedo Neto & Teixeira, 2009; Scott & Gray, 2010) The last reason why training with a dynamic moment of inertia can improve the swing speed is because we need to train the power component of the baseball athletes. The inertia training load may be advantageous for increasing power. (Djuric et al., 2016)

The results in our study share some similarities with previous studies that demonstrated a heavier bat leads to a slower swing speed. Baseball players and coaches should be warned about the potential decrease in swing speed that is happening to the players every at-bat when warming up with a weighted donut. We believe that the fact that the dynamic moment of inertia bat can help players swing faster is due to its the change in weight during the swing of the bat. First of all, the overall weight of a dynamic moment of inertia bat can be adjusted to be equal to the weight of any player's normal bat weight. Another advantage is the resistance of the moving weight can be adjusted for every player. The variable resistance bands force the player to always maximize their speed because if the player slows down, the elastic will pull on the weight and increase the resistance to the swing. Therefore, the faster the player swings, the easier the swinging becomes.

4.1 PRACTICAL IMPLICATION:

In conclusion, the use of a dynamic moment of inertia bat is an effective tool for baseball player to warm-up instead of a weighted bat/donut. Coaches should consider the use of different warm-up tools to avoid the kinesthetic illusion and facilitate improved swing speeds. Players and coaches should pay a close attention to their swing speed to promote performance.

4.2 COMPETING INTERESTS STATEMENT

This study was funded through the MITACS grant IT IT15640. The Mitacs is a program that pairs inventors to independent researchers. The Mitacs program will help inventors and corporations to fund private research in partnership with universities.

CHAPTER 3: WARMING UP WITH A DYNAMIC MOMENT OF INERTIA BAT CAN INCREASE BAT SWING SPEED IN COMPETITIVE FEMALE SOFTBALL PLAYERS

Canada has had a softball team play in every of the Olympics since 1996 and has won several medals at the Pan American games however there is very little research and support for them in this area. (Softball Canada, 2021) Not many studies have included female softball participants when trying to improve swing speed with new devices or training. This leads to a much higher representation of studies looking at male baseball athletes. While most softball players warm up with a weighted bat, there is evidence to suggest the warming up with a weighted bat can decrease swing speed during the at bat. Even though the bat feels lighter after warming up with the weighted bat, this is referred to as the kinesthetic illusion. (Nakamoto et Al., 2012; Ohkoshi & Kikuchi, 1980) In previous studies, it has been suggested that female athletes may show differences when compared to male participants. (Hennessy & Kilty, 2001; Nimphius et al., 2010) Oreščanin and Hraski suggested significant differences existed in bat swing kinematics between male and female softball athletes. (Oreščanin & Hraski, 2018) Warming up with a dynamic moment of inertia bat may not decrease the swing speed and therefore improve the bat swing speed and resulting performance of the players which would have a significant impact on the team. (Hung et Al., 2004; C. Liu et al., 2011) Our previous studies have indicated an increase in swing speed after using the dynamic moment of inertia bat. We want to make sure that female athletes also get the opportunity to try this new prototype. Gender equity and equal representation is essential for us. We previously studied male baseball players but based on the literature, we need to include female participants to get an accurate idea of the impact that a dynamic moment of inertia bat can have on competitive athletes in softball. Male and female athletes have multiple differences. These differences are anatomical, biomechanical and neuromuscular differences. (Chappell et al., 2002; Henry & Kaeding, 2001; Lephart et al., 2002; Vescovi & Mcguigan, 2008) We wanted to include competitive female athletes because Butler et al. concluded that performance deficits in females may not become apparent until achieving a certain level of loading. (Butler et al., 2014) We also wanted to expose the research world to young female athletes and support them in their quest to be the best athletes possible. Softball in Quebec and Canada has been successful despite the limited support and research on their performance.

The purpose of our study was to determine if warming up with a dynamic moment of inertia bat could improve the swing speed compared to warming up with a weighted bat with softball participants.

Subjects

This study was approved by the university ethics committee (IRB #30010037) and is in accordance with the American College of Sports Medicine's policies with regard to animal and human experimentation. The participants were informed of the benefits and risks of the investigation prior to participating. All subjects completed the institutionally approved informed consent document to participate in the study. For subjects under the age of 18, parents or guardians also provided written informed consent and a permission to videotape the participant during this study. Twenty-eight subjects (age = 15 ± 0.8 years) were recruited from a provincial female softball team. Our inclusion criteria included: all females, with similar softball experience, currently training with the provincial softball team and no current injuries or conditions that would affect the baseball swing. Our exclusion criteria included: players who were injured before the beginning of the study or during the study, and if the player had already been training with a dynamic moment of inertia device for some time before the start of the study. The objective of this study is to analyse the effect of warming up a dynamic moment of inertia bat prototype versus a heavy bat warm-up.

Methods

The following method is the same as for the baseball study (chapter 2) but tailored to softball athletes. Using a repeated measures study design, our experiment recorded the swing speed of competitive softball players after the use two types of warm-up tools. One warm-up tool was a weighted bat that was the equivalent to the weight of two regular bats. The other warm-up tool was a prototype that used a dynamic moment of inertia to apply a resistance during the swing. The dynamic moment of inertia bat has a customizable weight. Figure 4 shows the dynamic moment of inertia prototype used in this study. Every ring on the prototype is removable to allow the players to adjust the weight of the dynamic moment of inertia bat to weight as much as their normal bat. Since the prototype can have an equal weight to the normal bat, we should avoid creating a kinesthetic illusion. The weights are all held on together and move as one. The weights can freely move along the shaft of the bat during the swing. The dynamic moment of inertia bat forces the players to swing as fast as possible because the weight is attached to the grip by elastics. Since the weight is attached to the grip, this prevents the weights to be influenced by gravity and sliding to the end of the bat by itself. If the player doesn't swing fast enough, the weight will not move. The goal of the player during the warm-up is to focus on the timing of the swing. The players must focus on the weight reaching the end of the bat at the exact time where the bat would make contact with the ball during a real swing. If the player slows his swing, the resistance bands will pull back on the weights and this will prevent the weights to hit the end of the bat. The feeling will not be the same to the player the player would know that his current swing was not fast enough.

Swing speed measure – High speed camera:

The following method is the same as for the baseball study (chapter 2) but tailored to softball athletes. Every swing was measured using two separate tools. The first tool that we used was a high-speed camera filming at 600 frames per seconds. The camera we used was the CASIO EXILIM Pro EX-F1 (Casio Computer Co., Ltd., Tokyo, Japan). The camera is positioned over the player's head; where we can see the distance markers on the floor, their softball bat, and the ball on a tee (see figure 8). This method has been widely used in past research and will give comparable results to a motion caption system. (Gilmore et al., 2019; P. Maletsky et al., 2007) The ICC for the analysis of angles using a high-speed video analysis with the CASIO Exilim camera was reported between 0.803 and 0.986. (Oyama et al., 2017) Based on past research, the minimum required recording frame rate for baseball is 480 frames per second. (Pueo, 2016) We chose to use 600 frames per second for this study to have a better chance in having a clear motion of the bat. After each swing, we transferred the video files to a computer. We used the Kinovea software (Charmant, 2019 Kinovea Version 0.8.15) for the video footage analysis. Kinovea has previously been validated as a tool to assess time-related variables. (Balsalobre-Fernández et al., 2014) The results of a past study suggest that Kinovea is a valid, precise and reliable (both inter- and intra-rater) program with which to obtain angles and distance data from coordinates. (Puig-Diví et al., 2019) The ICC for the Kinovea software is between 0.79 and 0.997. (Puig-Diví et al., 2019) Since the name of the file that has the slow-motion footage doesn't include the name of the player, all of the calculations were done by keeping that file name. The encryption allowed the researcher who was calculating the swing speed to be blinded and could not determine which group the participant was in.

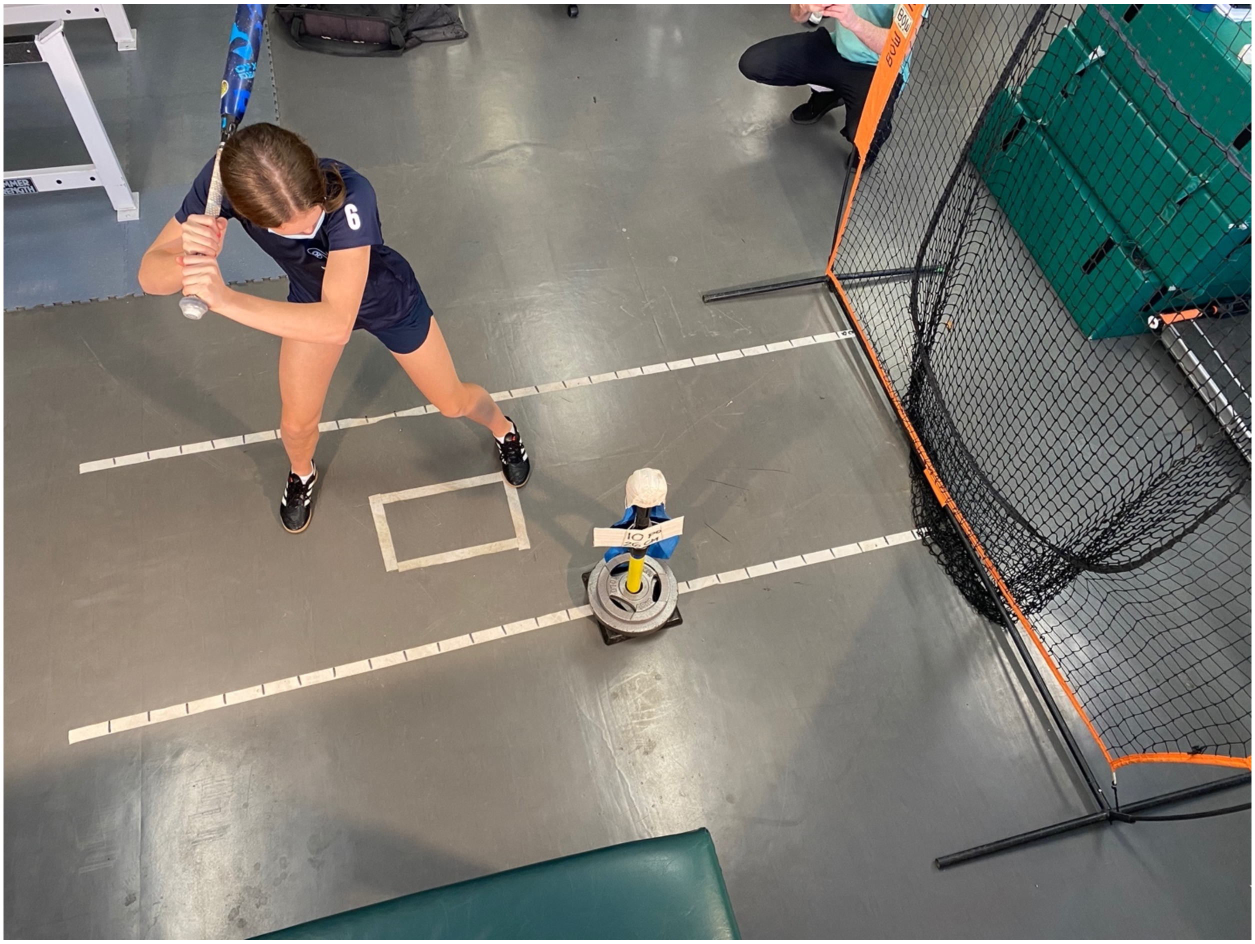


Figure 8 . A picture of the data measurement set-up We can see distance markers on the floor to facilitate the calibration of the Kinovea software. We can see a participant holding his own bat just before he swings towards a ball into a net from a tee.

Since the baseball research set-up from chapter 2 was proven to work as expected, we used the same method for this softball study. We used the Kinovea software to analyze the high-speed footage. In order to obtain precise results, we were required to calibrate the software with known distance markers on the floor and on the baseball tee in order to calculate the linear displacement. To be consistent, we used the last frame before the bat contacted the ball on the tee. To standardize the swing for every player, we used the 15 frames that preceded the ball contact. This method was used in previous studies measuring bat swing speed. (Lyu & Smith, 2018; Williams et al., 2019) The Kinovea software has a function that tracks an object's displacement. We used this function to track the 'sweet spot' on the bat. A screenshot of the computer screen view is available in the appendix as figure 6. The sweet spot was determined to be 6 inches away from the end of the bat to be consistent with the BLAST sensors.

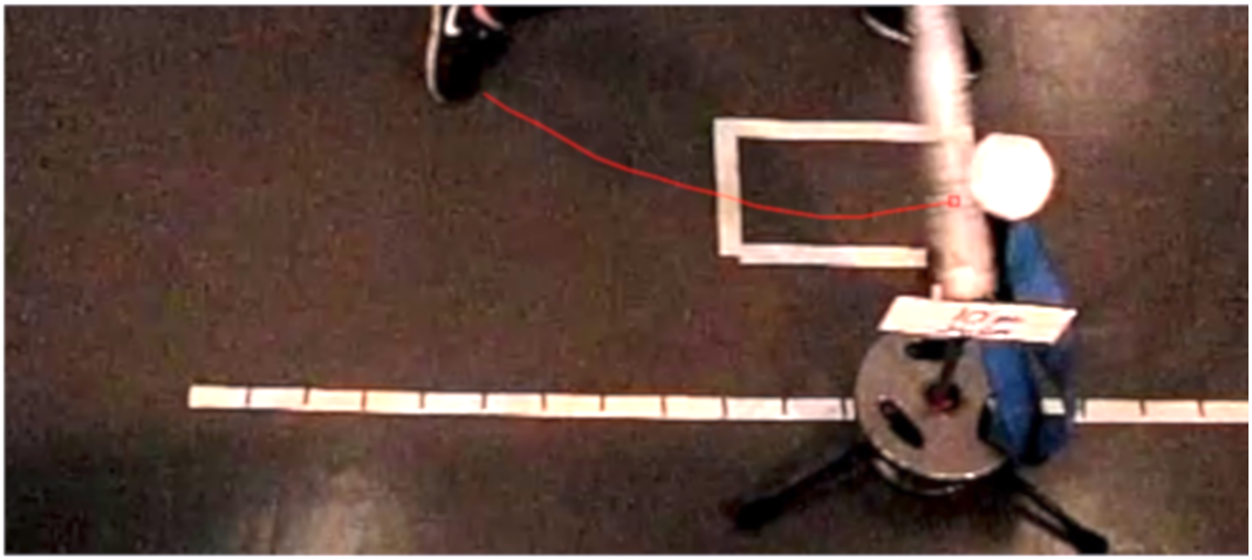


Figure 6. A screenshot from the Kinovea software illustrating the motion tracking function. This function automatically follows a precisely selected point (sweet spot of the bat in our case). The red line illustrates the path of the sweet spot of the bat over the last 15 frames before it hit the ball.

Once the total linear displacement of the sweet spot was determined through 15 frames, we were able to calculate the swing speed of each swing with the formula below:

$$linear\ swing\ speed\ (mph) = \frac{distance\ travelled\ by\ the\ sweet - spot(mi)}{frame\ duration\ (h)}$$

Equation 1. This equation was used to calculate the bat swing speed using the high-speed camera footage in Kinovea.

We followed the same method for both warm-up methods for a total of 4 swings per participant.

<u>Swing speed – inertial sensors</u>

Recently, the BLAST® sensor was suggested to be the most accurate device on the market to measure swing speed in baseball. (Aguinaldo, 2016) When comparing the results from the motion analysis system to the BLAST® sensor, the BLAST® sensor had the lowest error margin from all of the models compared. The relative error was 5% compared to the motion capture. (Aguinaldo, 2016) We decided to use the BLAST® inertial sensors because every softball player from the team already had one on their bat. Every BLAST® inertial sensor was paired to the athlete's phone. Every BLAST® inertial sensor was calibrated to the participant's normal bat that they used to swing at the ball. Using the BLAST® inertial sensors had many advantages. They allowed us to confirm our speed calculations with the high-speed camera, to instantly give the players an estimation of their swing speed once they completed the study and it allowed us to re-take any bad swings. We did not have to re-take any swings for this study.

Procedures for the warm-up swinging protocol:

The girls from the softball group followed the same steps required for the baseball participants. We welcomed every player in groups of 3 based on their position and hand dominance. The grouping of players was done to avoid having players wait for too long before doing their test after the warm-up. On the batting tee, we placed a ruler measuring exactly 25cm. The 25cm ruler is a fixed measurement used to calibrate the high-speed camera footage and the Kinovea software. We also noted the length of the softball bat (32.8 ± 0.6 inches). We then noted the limb dominance for every player (3 lefthanded players and 25 righthanded players). We took the time to demonstrate every player how to use the dynamic moment of inertia bat. Taking the time to explain every player how to use the prototype was important to avoid any misuse during the warm-up. The explanations also made sure that every participant knew what to expect and how fast they had to swing during their warm-up. We made sure that the prototype bat weight was equal to the player's bat weight that they will be using to swing for the analysis to avoid creating the kinesthetic illusion. We filmed two trials per warm-up tool per player. Every player had 4 filmed trials in total. Every player completed the same warm-up routine which consisted of 3 swings at 75% max swing speed followed by a rest period. This rest period was only to leave enough time to the participant currently getting filmed to finish their trials and replace the ball on the tee. To measure the bat swing after the warm-up we asked players to swing at a ball on a tee with the same intensity that the participants would do during a game when facing the opposing team's pitcher. The use of a baseball tee is common in baseball and has been used in previous swing speed analysis studies. (Dowling & Fleisig, 2016; Williams et al., 2019) While hitting from a tee has some limitations, hitting from a tee allows us to standardize some aspects of the swing to focus on the general swing mechanics. (Dowling & Fleisig, 2016) The tee is be placed one step away from the player and the height is adapted to the waist level of every player. The set-up for the swing speed analysis is shown in Figure 8. Every player has 30 seconds in-between each repetition to rest and reset their position. The 30 seconds rest replicated well a real in-game scenario as determined by a past study from Baker et all in 2003. (Baker et al., 2003) Once the participants had completed the 2 swings, the participants had to change their bat type and warm-up again for the next measurements. (3 warm up swings – 1^{st} recorded swing – rest– 2^{nd} recorded swing – new bat warm-up with 3 swings – 3^{rd} recorded swing – rest – 4^{th} recorded swing). The swinging protocol is based on a previous study made by Szymasky in 2011. (D. J. Szymanski et al., 2011) The warm-ups were completed with either the prototype or the heavy bat, but every recorded swing is with their normal bat.

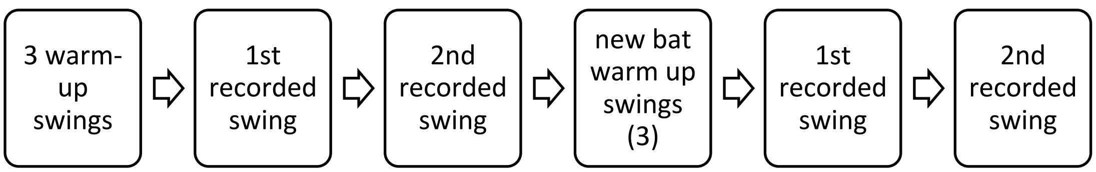


Figure 7. Order of testing for every player.

<u>Swinging instructions:</u>

A good quality swing for this study is that the player is able to swing as fast as possible while still hitting the ball into a catch net. For safety reasons, the ball was attached to the tee with elastics to prevent an accidental batted ball to miss the net. The participants swung at the ball on the tee as fast as if they were attempting to hit a ball from a pitcher in a game. An example of a "not good" swing would be if the ball is batted to the side, slightly touched, or completely missed. A bad swing would also be in the case that the sensors or the camera didn't record the swing. No participant had their swing excluded in our study.

<u>Statistical Analysis:</u>

All data were analyzed with SPSS version 26.0 (SPSS Incorporated, Chicago, IL) with a-priori alpha level for significance of $\rho \leq 0.05$. We compared both average swing speeds using a paired t-test. We estimated our power using G*Power program (v.3.1) and our sample size is very close to previous studies that have evaluated swing speeds for softball teams with approximately 28 players. (Szymanski et al., 2009b)

Results

There was a significant increase in swing speed after warming up with the dynamic moment of inertia bat compared to warming up with the weighted bat. The paired t-test to test for a difference between both warm-up methods was significant ($p= 0.0001$). On average there was an improvement of 2.26% (95% confidence interval: 52.8 to 56.4mph)
). Our effect size (Cohens d) is 0.248 which is considered small.(Fritz et al., 2012) The average swing speed using the dynamic moment of inertia bat and the heavy bat is detailed in table 4. Swing speeds measured with the high-speed camera of every participant are shown in table 5.

Average swing speed after warm-up with the prototype	SD	Average swing speed change after warm-up with the heavy bat	SD	Effect size (Cohens d)
24.94m/s (53.67mph)	2.20m/s (4.47mph)	24.41m/s (53.69mph)	2.12m/s (4.47mph)	0.248

Table 4. This is a Summary table describing the average swing speed with the two different warm-up tools and the standard deviations in meters per seconds of the 28 softball players. The effect size is also displayed.

#	Prototype swing speed m/s	Heavy swing speed m/s	% Change	#	Prototype swing speed m/s	Heavy swing speed m/s	% Change
1	27.17	26.50	2.56%	15	27.55	26.54	3.81%
2	23.36	23.13	0.97%	16	24.39	25.66	-4.98%
3	23.77	23.38	1.66%	17	27.22	26.46	2.89%
4	20.27	21.12	-4.04%	18	23.28	23.98	-2.93%
5	24.97	25.09	-0.48%	19	25.32	24.65	2.72%
6	25.53	24.08	6.02%	20	26.92	26.64	1.02%
7	24.56	21.98	11.73%	21	26.04	23.37	11.44%
8	20.89	20.59	1.45%	22	21.48	20.61	4.25%
9	24.59	22.87	7.48%	23	24.93	23.77	4.85%
10	28.18	27.30	3.21%	24	27.50	26.44	4.02%
11	28.34	29.36	-3.47%	25	22.94	23.03	-0.39%
12	26.36	24.91	5.80%	26	22.78	23.14	-1.55%
13	26.16	26.70	-2.01%	27	25.80	23.95	7.71%
14	27.17	26.50	2.56%	28	22.11	22.88	-3.34%

Table 5. Post warm-up swing speed comparison for a fixed moment of inertial compared to a dynamic moment of inertia for 28 elite softball players.

Discussion

In conclusion, despite having a slower swing speed compared to the baseball players from chapter 2, the softball athletes did benefit from similar improvements. The use of a dynamic moment of inertia bat is an effective tool for softball player to warm-up instead of a weighted bat/donut. Coaches should consider the use of different warm-up tools to avoid the kinesthetic illusion and facilitate improved swing speeds. We believe that the improvements are due to the same physiological processes described in chapter 2. When the participants use a heavier bat than what they are expected to use at-bat, they prepare their body to swing slower due to the computation theory stated by Blakemore in 1999. (Blakemore et al., 1999) If players are able to counter the kinesthetic illusion while also benefiting from the computation theory when they use a dynamic moment of inertia bat when they warm-up, this could be the best warm-up tool available to baseball and softball players at the moment. Players and coaches should pay a close attention to their swing speed to promote performance.

CHAPTER 4: A 6-WEEK TRAINING PROGRAM IMPLEMENTING SWINGING A DYNAMIC MOMENT OF INERTIA BAT FOR UNIVERSITY BASEBALL PLAYERS

Specific resistance training attempts to provide a training stimulus that mimics actual game motions and bioenergetic systems used to perform the activity. (Szymanski et al., 2009b) We created a training method that incorporates a 6-week whole-body strength and conditioning program combined with bat swing training featuring a dynamic moment of inertia bat. We already did some warm-up studies (chapter 2), but this study is focussing on a long-term training program and the added benefits of using a dynamic moment of inertia bat to improve baseball swing speed. The training program is detailed in the Appendices. Our training program was created based on two things. We created our training program was created with the Szymanski's suggestions and the Atlanta Braves 2006 off-season program. Here are Szymaski's 12 take-home messages to improve swing speed (Szymanski et al., 2009a) and how we addressed his recommendations for our study:

1. It is suggested that to obtain optimal bat swing velocity before stepping into the batter's box, a high school or collegiate baseball player should warm up with a specific, weighted bat that is identical to or very close to the same weight as his standard game bat (30 oz), and the player should replicate his standard range of motion while swinging a bat at high game velocity.
    a. To address this, the weight used with the prototype is equal to the weight of a normal bat.
2. Furthermore, it is suggested that swinging a very light (27 oz) or heavy (34 oz) baseball bat before hitting may actually have a negative impact on a baseball player's bat swing velocity.
    a. To assess for the baseline swing speed, we used a heavy bat for the warm-up. Every player then had to use their normal baseball bat to hit the ball. This method is replicating the in-game situation and protocol that players go through.
3. The commercial donut ring, which is the most commonly used warm-up device in baseball in the on-deck circle, should be avoided because it produced the slowest bat swing velocities.

    a. In our study, we did not use a donut. Instead, we asked the players to use two baseball bats to warm-up.

4. For untrained individuals or those who are not in bat swing condition, swinging a standard game bat at least 100 times per day, 3 times a week, for 6–8 weeks will increase bat swing velocity.
    a. For our 6-week training study, the athletes performed on average 120 swings per week (2x15 swings bilaterally) (2x/week) for 6 weeks. They also performed an un-monitored number of swings for the rest of the week during practices. They therefore met the recommendations mentioned above.
5. Specific resistance training with underweighted and over-weighted bats will increase bat swing velocity in highly experienced high school and college players. The largest improvement in bat swing velocity (10%) was found after taking 150 swings, 4 times a week, for 12 weeks with baseball bats weighing ±12% of standard game bat weight. However, it is advisable that the athlete be well conditioned before starting this type of training.
    a. Because of our limitations, we could only do 120 swings per week spread over 2 practices a week.
6. Bat swing velocity can be increased after engaging in resistance training programs that incorporate, as a minimum, training 3 times per week for 6 weeks of general resistance protocols for high school baseball players.
    a. We incorporated a supervised training program 2x/week for 6 weeks.
7. To maximize the effect of resistance training programs on bat swing velocity, training experience and age must be taken into account.
    a. All our athletes have similar training and baseball experience.
    b. All our softball athletes were part of the same teams.
8. Additional forearm and grip strength does not contribute to further improvements in bat swing velocity for high school baseball and college softball players.
    a. Our supervised training program included full body exercises and did not focus on forearm or grip strength training.

9. Performing additional rotational medicine ball exercises explosively 2 times a week in a progressive manner that replicates the bat swing motion will improve bat swing velocity for high school baseball players.
    a. This type of exercises was included in our training program.
10. Performing additional forearm and grip exercises, swinging bats underwater, and wearing overweight forearm devices have not contributed to further increases in bat swing velocity for high school or college baseball/softball players or for college students compared with ‘‘normal’’ baseball/softball training.
    a. The dynamic moment of inertia bat weighs the same as the participants’ normal bat.
11. Players with the greatest bat swing and batted-ball velocities have greater strength, power, and lean body mass.
12. Because the baseball/softball swing is a sequential, rotational kinetic link movement that incorporates the entire body from the legs, trunk, and shoulders to the arms, one should mimic the swing with sport-specific exercises. To do this, one should place additional resistance on the bat itself or throw medicine balls explosively to produce greater increases in bat swing velocity.
    a. This is addressed in the training program.

We were able to get access to the Atlanta Braves strength and conditioning program for the 2006 off-season program. (Slate, 2006) The off-season program helped us by motivating our participants by letting them know they would train like pros. Our regimen differs from previous studies and protocols because it is short in duration, and it includes training with a prototype bat as opposed to a regular or a heavy bat. In our analysis, we focus on the improvements in bat swing speed after using our program. First, we examined bat swing speed in order to assess any positive changes our strength program has on swing speed.

The goal of this study was to analyse the effect of training with a dynamic moment of inertia bat prototype on swing velocity over a 6-week training period.

Participants

Our cohort consisted of 12 collegiate baseball players. Only 4 players could complete the study due to the COVID-19 pandemic stopping us from continuing our in-person research projects. It is important to mention that all 12 players completed the 6-week training program and would have completed the full study if COVID-19 did not force us to cancel the following day of data measurement which was to measure the bat swing speed of the last players. The players were interested in the research, motivated by the project and were happy to be supervised while they trained. The participants were included in this study if they were interested in a supervised full-body workout. The participants had to be part of the Concordia University baseball team.

	Sample size	Average age	Standard deviation
Completed the full study	4	21 years old	2.58 years
Completed the training program	8	20.63 years old	1.92 years

Table 6. Description of the enrolled participants. Described here is the group size and the age of the participants.

Swing speed measure – High speed camera:

The methods used for this research is the same as the research projects in chapter 2 and chapter 3. The weight of the heavy bat is equal to two bats. We chose to use the same method for this study as well because the players that participated in this study also participated in the warm-up study for competitive baseball players from chapter 2. For this study we had access to two methods of swing speed measurement.

Swing speed – inertial sensors

The first method to calculate the swing speed is the BLAST sensor. Inertial sensors are widely used because of the easiness and quickness of use. Recently, the BLAST® sensor was suggested to be the most accurate device on the market to measure swing speed in baseball. (Aguinaldo, 2016) When comparing the results from the motion analysis system to the BLAST® sensor, the BLAST® sensor had the lowest error margin from all of the models compared. The relative error was 5% compared to the motion capture. (Aguinaldo, 2016) The blast sensor was also used to quickly exclude bad swings when the participants were in front of the camera.

The second method that we used was a high-speed camera filming at 600 frames per seconds. The high-speed camera is the most precise measurement tool that we used in this study. We used the CASIO EXILIM Pro EX-F1 (Casio Computer Co., Ltd., Tokyo, Japan). The camera is positioned over their head; where we can see the distance markers on the floor, their baseball bat and the ball on a tee. (see figure 5 in the appendices) This method has been widely used in past research and will give similar results compared to a motion caption system. (Gilmore et al., 2019; P. Maletsky et al., 2007) The ICC for the analysis of angles using a high-speed video analysis with the CASIO Exilim camera was reported between 0.803 and 0.986. (Oyama et al., 2017) We decided to exceed the recommendations from Pueo et al. and instead of going with 480 frames per second, we chose to go with 600 frames per seconds to improve the precision of our calculations. (Pueo, 2016) After each swing, we transferred the video files to a computer. We used the Kinovea software (Charmant, 2019 Kinovea Version 0.8.15) for the video footage analysis. Kinovea has previously been validated as a tool to assess time-related variables.(Balsalobre-Fernández et al., 2014) The results of a past study suggest that Kinovea is a valid, precise and reliable (both inter- and intra-rater) program with which to obtain angles and distance data from coordinates. (Puig-Diví et al., 2019) The ICC for the Kinovea software is between 0.79 and 0.997. (Puig-Diví et al., 2019) The file name is encrypted automatically by the camera. The name does not contain the name of the player or the warm-up tool that was used. All calculations were done by keeping that file name. This encryption allowed the researcher who was calculating the swing speed to be blinded and could not determine which group the participant was in.

To get accurate results in Kinovea, we calibrated the software with distance markers. The distance markers were on the floor and on the baseball tee in the lab. The distance markers are visible on the video footage and they are used to calibrate the software to precisely calculate a distance. To be consistent, we used the displacement from the 15 frames that preceded the last frame before the bat touches the ball on the tee. This method was used in previous studies measuring bat swing speed. (Lyu & Smith, 2018; Williams et al., 2019) The Kinovea software includes a function that tracks an object's displacement. A screenshot of the screen view is available as figure 6. We used this function to track the 'sweet spot' on the bat. To stay consistent with the BLAST sensors, the location of the sweet spot is determined by a point located 6 inches away from the bat. The total linear displacement of the sweet spot was determined through 15 frames, we were able to calculate the swing speed of each swing with the formula below:

$$linear\ swing\ speed\ (mph) = \frac{distance\ travelled\ by\ the\ sweet - spot(mi)}{frame\ duration\ (h)}$$

$Equation$ 1.This equation was used to calculate the bat swing speed using the high-speed camera footage in Kinovea.

The swing speed was calculated for both trials for one warm-up method (either the dynamic moment of inertia bat or the weighted bat), we averaged the result. We followed the same method for the other warm-up method during the two subsequent swings.

Due to a high discrepancy between the player's baseline swing speed values, because we only used one group of athletes and the multiple means and variables to be calculated we opted for an analysis using a repeated measure ANOVA.

Results

Bat Swing Speed (BSS) After a Bat Swing Warm-Up with a Prototype and a Heavy Bat				
Bat	**N**	**Mean BSS W0(mph)**	**Mean BSS W6(mph)**	**Mean increase in BSS (mph)**
Prototype	4	58.9 ±7.7	61.9 ±8.0	2.9
Heavy bat	4	56.8 ±10.1	61.2 ±7.9	4.3

Table 7. Bat Swing Speed Results at Week 0 and Week 6

Swing Speed

In total, 4 players were tested for swing speed at week 0 and week 6 with both a bat prototype and a standard heavy bat. Even though the initial swing speed values were faster when using the bat prototype as opposed to the heavy bat, the mean values show a general increase in swing speed between week 0 and week 6, whether it is with the bat prototype or the heavy bat. The players increased their bat swing speed on average by 2.97mph with when using the prototype bat and increased the bat swing speed by 4.312mph when using the heavy bat after the 6 weeks program. The p value show that this increase in bat swing speed pre and post 6 weeks program is statistically significant (p=0.029). However, there was so statistically significant difference between the results of the two types of bats. Both bats showed a significant increase in swing speed.

Our bat swing speed improvements (+2.97mph for the prototype warm-up and + 4.3125mph for the heavy bat warm up) are comparable to the statistically significant results of other studies using a training program and batting practice to improve bat swing speed. (Hughes et al., 2004; D. J. Szymanski et al., 2006)

As highlighted above, the bat force necessary to increase bat swing speed is generated by the hip, torso and upper extremities as opposed to the forearms and wrists themselves. (Hughes et al., 2004) Hence the importance of having incorporated in our training regimen exercises that target torso, hip and upper extremities. Our results clearly show that this training regimen significantly increases swing speed.

The novel element we bring to the research of bat swing speed is the use of a bat prototype as a warm-up method as opposed to a standard heavy bat. Our results show that the initial bat swing speeds were higher after having warmed-up with the prototype vs. the standard bat. Even though the p value does not show any significant difference between the improvements made using the two different types of bats, a baseball player looking to increase his speed can benefit from using this bat prototype. The combination of the bat prototype warm-ups and our strength and conditioning regimen clearly positively impacted bat swing performance. A picture of the prototype can be found in the appendices - figure 4.

Discussion

The purpose of this study was to determine the effects of a 6-week strength and conditioning program and swing training on the bat swing speed of collegiate baseball players. Our results showed an improvement on bat swing speed following the 6-week training program. We know that in order to improve a baseball player's bat swing, one must work on the hips, torso and upper extremities which generate and transfer the power to the bat. Our 6-week strength and conditioning program with batting warm-up addressed those requirements and provides tangible results that increases bat swing speed in collegiate athletes. This program is accessible with little equipment needed while targeting the body as a whole. It is easy to implement by coaches as only two sessions per week for as little as 6 weeks have shown to provide beneficial results. Using a dynamic moment of inertia bat as a training device has also shown to provide faster bat swing speeds. The dynamic moment of inertia bat should be a tool that coaches consider using to train their athletes.

We decided to include a general strength and conditioning program in addition to the swing training for multiple reasons. The first reason is to allow the players to maintain their physical shape and allow them to train while the study is running. This will prevent de-training that could happen if we only focussed on swing training for 6 weeks. The second reason is to standardize every player's training program in order to create a basic training program that is applicable to everybody and has a holistic approach. The third reason is to better compare our results with other studies that studied swing training in addition to strength training or studies with high-level athletes who already train on a daily basis and only add swing training on top of their usual routine. Because of the reasons mentioned previously, we are confident that our results are valid, represent real-life experiences of competitive baseball players and demonstrate the impact that using a dynamic moment of inertia bat can have in conjunction to regular strength training to improve swing speed in competitive baseball players. Training the power of the swing with a dynamic moment of inertia bat is possible because the weight is equivalent to the normal bat of every player, but the resistance is only applied to the speed of the movement. The participants have to swing faster to counterbalance the strength of the resistance bands while keeping their timing and swinging mechanics equivalent to a normal swing. It is possible for the players to know if their timing is good because they can hear the weights hitting the extremity of the bat. The participants are able to know if their timing was off or if it was a good swing when they hear the sound at the location where the sweet spot would make contact with the ball during a normal in-game swing.

When we compare our results to a previously published study also using a dynamic moment of inertia bat, we get lower results. The study that was published by Liu et Al. 2011 had the players use the prototype for 12 weeks and they had a bigger sample size (17 players). (C. Liu et al., 2011) We believe the results from our study are statistically and clinically significant even if the sample size is low (N=4) because the players managed to improve their swing speed and always had a faster swing speed than the heavy bat even after 6 weeks. The strength training in conjunction to swing training has been proven to improve bat swing speed. This is a superior option to previously used materials such as heavy bats or baseball weighted donuts. In order for coaches or athletes to get a faster baseball bat swing speed, a great focus on strength training and an actual swing training for at least 6 weeks has been demonstrated to help attain that goal.

CHAPTER 5: THERMAL IMAGING PROFILE OF UNIVERSITY BASEBALL PLAYERS AFTER A BASEBALL WARM-UP FOLLOWING A 6-WEEK TRAINING PROGRAM

One of the most common procedures in sports is the warm-up. Whether athletes execute the warm-up to get mentally and physically ready for their sports, there's no real way to objectively measure the progression of the warm-up. Athletes and coaches will do warm-ups based on their personal experience and don't rely on research. (Fradkin et al., 2010) A warm-up is very important as warming-up has been correlated with attaining the optimal muscle temperature required for muscle function (Mohr et al., 2004) and warmed-up muscles are less susceptible to injuries. (Fradkin et al., 2010) Finding an objective measure the physiological response to warm-up is very interesting. With the improvement in technology of portable infrared cameras, the measurement of skin temperature response during warm-up is something that we explore in this project. Previous studies have been detecting variations in skin temperature over active and non-active muscles during different types of physical activity (Neves et al., 2015). Having a look at the skin temperature variations in our baseball players may give important information on the working muscles during a bat swing. We may also confirm the theories that with a high-intensity warm-up, we observe a decrease in skin temperature. (Adamczyk et al., 2016; Chudecka & Lubkowska, 2010; Escamilla-Galindo et al., 2017; Fernández Cuevas et al., 2014; Priego Quesada et al., 2016) Since the skin temperature of individuals responds differently depending on the type of activity performed (Neves et al., 2015), if we consider performing quick and short bouts of powerful bat swings as a form of high intensity anaerobic activity, we could make the hypothesis that we will observe a difference in skin temperature of active muscles before and after bat swing. Therefore, using skin temperature could potentially be used as an indicator of which muscles are under stress during bat swing. The objective of this study is to see the physiological changes due to warming-up with a DMOI through an infrared camera.

Procedures

The first step was the baseline testing on week one. Every player had to sign a consent form and a research agreement prior to starting the study. After agreeing to participating in our study, each participant was scheduled an individual evaluation in the research lab. Every participant had to come wearing a T-shirt and shorts. The player was then required to take his shirt off and remain standing for a duration of 15 minutes in order to adapt to the room temperature. This 15 minutes is called an acclimatisation phase and it is a vital phase of the Glamorgan protocol. (Ammer, 2008; Marins, Moreira, et al., 2014; Moreira et al., 2017) The infrared camera used was a FLIR C3 (FLIR® Systems Inc., Wilsonville, Oregon, USA) with a resolution of 80x60, a thermal sensitivity of 0.1 °C, and accuracy of ±2%. The emissivity was set to 0.98 for all subjects and is in accordance to international consensus. (Fernández-Cuevas et al., 2015; Marins, Fernandes, et al., 2014; Moreira et al., 2017) The camera was positioned 2 meter away from the participants. The temperature in the room was 22°C. Infrared images were taken by a certified thermographer. Following the 15 minutes acclimatisation phase, infrared pictures were taken of both the torso and the lower extremities. Pictures were taken anteriorly and posteriorly for the torso and lower extremities. The player was instructed to perform 3 sets of 5 bat swings bilaterally. Every player was instructed to swing as fast as they can with a baseball prototype. The baseball prototype weights the same as their own bat but features elastics that give a tactile feedback when the swing is fast enough. Following the bat swings, every participant is required to answer a questionnaire pertaining to their swinging experience. This questionnaire lasted approximatively 45 seconds to 1 minute. This questionnaire can be found in the appendix section. A post-warm-up set of Infrared images was taken in the same manner as before.

Following the same procedure, a second set of measurements will be taken 6 weeks later to validate the effect of a warm-up on skin temperature on trained athletes. During the 6-week period, the participants were taking part in a supervised general weight training program. The attendance was taken for every strength training session. Supervising and taken attendance allowed us to measure and monitor exercise compliance.

Participants

The group included 7 male baseball players from Concordia University. The group included 4 right hand dominant and 3 left hand dominant baseball players.

N=7	Mean (years old)	Standard deviation (years old)
age	20.29	2.21

Table 8. Description of the group size (N=7) and mean age of the participants.

Analysis

Once the infrared image is downloaded in the computer, we needed to compute the average skin temperature. To do so, we have selected regions of interests that will be constant with every participant. The summation of every area of interest will give us the average skin temperature for every picture. The regions of interest are illustrated in figure 9 below. This method of analysis is used in the Glamorgan protocol(Ammer, 2008) and other studies such as Adamczyk et al. 2016 (Adamczyk et al., 2016) and has been enhanced in recent years with the help of artificial intelligence. (Moreira et al., 2017) A repeated measure ANOVA was used to analyze the skin temperature changes of the anterior/posterior torso as well as the anterior/posterior legs displayed by the infrared imaging in 7 players. The statistical assumptions were verified and respected. Every participant was evaluated using the same regions of interests. The size of the areas of interest is based on anatomical landmarks. The area of the torso and the back are defined by the distance between the left and right acromioclavicular joints and the length is equal to the T1 vertebrae until the L5 vertebrae. The area for the arms was defined by the width of the arm and the length of the arm until the first rows of carpals. The anterior leg region of interest is the same for both the left and right leg. The region of interest starts at the infrapatellar tendon and finishes at the metatarsal bones. The width of the region of interest is equal to the width of the calf.

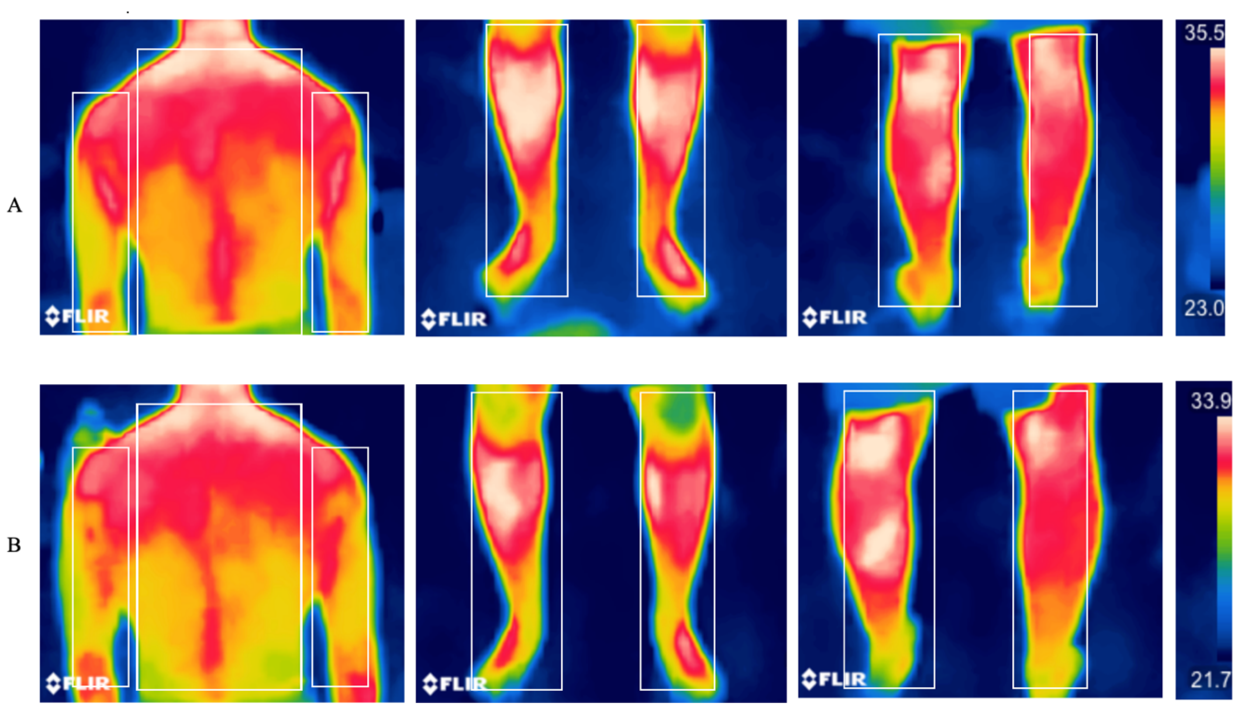


Figure 9. To understand the pictures better, the skin surface temperature will go from dark colours such as purple or blue to warm colours such as red or white when the skin temperature goes from cold to warm. A white region is therefore way warmer than a green region. A scale is also available on the right-hand side to get an idea of the maximum and minimum values. Row A pictures an athlete before the warm-up. Row B pictures the same athlete after the warm-up. We can see from the scales and the colour variation that the temperatures decreased after the warm-up. Regions of interest are highlighted by white squares. The average skin temperature was calculated using these regions of interests.

Results

Mean skin surface temperature per body area (°C) before vs after bat swing warm up at baseline (W0) and after 6 weeks (W6)					
N	**Body area**	**Mean skin surface temp. before warm-up at W0(°C)**	**Mean skin surface temp. after warm-up at W0(°C)**	**Mean skin surface temp. before warm-up at W6(°C)**	**Mean skin surface temp after warm-up at W6(°C)**
7	Ant. Torso	32.000 ±0.523	31.043 ±1.372	31.529 ±0.616	30.943 ±0.513
7	Ant. Leg	29.100 ±1.663	28.543 ±0.870	29.293 ±0.952	29.286 ±0.691
7	Post. Torso	32.176 ±0.715	31.100 ±1.293	31.057 ±0.799	31.129 ±0.446
7	Post. Leg	30.021 ±1.325	29.200 ±1.144	30.471 ±1.118	30.607 ±0.729

Table 9. Mean Surface Skin Temperature Using Infrared Imaging at Week 0 and Week 6

Mean temperature variation(°C) before vs after bat swing warm up at baseline (W0) and after 6 weeks (W6)				
N	**Body area**	**Mean variation before vs after warm-up at W0(°C)**	**Mean variation before vs after warm-up at W6(°C)**	**Avg variation for that body area b/w W0 and W6 (°C)**
7	Ant. Torso	-0.957	-0.586	-0.772
7	Ant. Leg	-0.557	-0.007	-0.282
7	Post. Torso	-1.076	0.072	-0.502
7	Post. Leg	-0.821	0.136	-0.343
			Total avg variation for all areas (°C)	-0.475

Table 10. Mean Surface Skin Temperature Variations Using Infrared Imaging at baseline (W0) and after 6 weeks (W6)

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
ant torso	Between Groups	4.979	3	1.660	2.372	.078*
	Within Groups	16.789	24	.700		
	Total	21.767	27			
back	Between Groups	6.153	3	2.051	2.716	.049*
	Within Groups	18.122	24	.755		
	Total	24.274	27			
ant legs	Between Groups	2.641	3	.880	.714	.481
	Within Groups	29.602	24	1.233		
	Total	32.243	27			
posterior legs	Between Groups	8.442	3	2.814	2.322	.297
	Within Groups	29.084	24	1.212		
	Total	37.525	27			

Table 11. Repeated measure ANOVA results. The ANOVA is compares the mean surface skin temperature variations using infrared imaging at baseline (W0) and after 6 weeks (W6).

Conclusion

To analyze the means, we used a repeated measure ANOVA. We used a repeated measure ANOVA because all measurements were done on the same group of participants. All assumptions were respected. The alpha level of significance was 0.05. For a result to be significant, the p-value had to be below 0.05. The mean results show an average decrease (-0.475°C) in surface skin temperature before and after a warm-up at week 0 and week 6. The p-value shows there is a statistically significant decrease in posterior torso skin temperature post bat swing warm up ($p = 0.049$) with a mean value of -0.574°C. The decrease in temperature of the posterior leg is not statistically significant but the p-value does show a trend in decrease in temperature ($p=0.078$). However, there was no statistically significant change in skin temperature for the anterior torso and anterior leg.

Our results are comparable to a 2014 study which observed a decrease in skin temperature ranging between 0.3 degrees and 0.8 degrees in 63% of their cases after having ran for 45 minutes. (Fernández Cuevas et al., 2014) A 2016 study by Korman which also found an early decrease in surface skin temperatures during speed endurance, suggests that the thermoregulatory mechanism of the body could be activated in order to eliminate heat (Korman et al., 2016), which would explain an initial drop in temperature. One thing to note in our study, is that the decrease in skin temperature of the posterior back post warm-up was mainly observed at week 0 (-0.853 degrees) as opposed to week 6 (-0.0963 degrees). In fact, most areas of the body showed larger decreases in skin temperature at week 0 as opposed to week 6. From the results we have gathered in this study, showing that the posterior torso had a significant decrease in skin temperature as opposed to other areas, we may be able to deduct that the muscles in that area are the active muscles. Further testing looking at specifically the posterior torso before and after bat swing warm-up may reveal more information pertaining to specific muscles' responses. Using a more precise camera that is specially created to measure skin temperature may give us more precise measurements.

CHAPTER 6 – GENERAL DISCUSSION

The main question that this thesis is trying to answer is: Can a dynamic moment of inertia bat improve the bat swing speed. Our study projects were able to answer this question. The dynamic moment of inertia bat prototype that we tested demonstrated significant advantages compared to the heavy bat during a warm-up. We were able to get significant increases in swing speed after warming-up with the dynamic moment of inertia bat for competitive baseball players. The dynamic moment of inertia bat was also shown to be effective for competitive softball players after only a warm-up. Our results are in accordance with previously published research paper that show an improvement in swing speed when using a dynamic moment of inertia bat instead of a heavy bat during the warm-up. We are confident to say that our swing speed results are valid and reflect the reality of competitive baseball players' swing speed. The swing speeds our participants were like past research on competitive baseball players. Based on the results of past studies and our current work, we think that every baseball or softball player should chose to warm-up with a dynamic moment of inertia bat to negate the effect of the kinesthetic illusion. If players that use a dynamic moment of inertia can swing faster, this could lead to an increase in home runs and better performances. Using a dynamic moment of inertia bat could give an advantage to the athletes that use the dynamic moment of inertia bat.

The second question that we answered was: Can a dynamic moment of inertia bat be used as a training tool to improve the swing speed in baseball over a 6-week training period. Our first studies wanted to know if a dynamic moment of inertia device could defeat the kinesthetic illusion during the warm-up. Since we now know that a dynamic moment of inertia bat will not hurt your performances, we wanted to know if it could be beneficial to improve the swing speed over a longer period of time. An improvement in performance that can withstand the test of time could be even more important than just a warm-up tool with transient results. If the dynamic moment of inertia bat is also a training tool, the improvement in performances could go further than a neurological adaptation. Our study implemented a full body training program to give the players a standardized training while we added the swing speed training using a dynamic moment of inertia. We found that players were able to improve their swing speed by a bigger amount when they trained with the dynamic moment of inertia bat compared to the improvement after a warm-up only. Our results are along what other studies have found when training with a dynamic moment of inertia bat over a long period of time. The dynamic moment of inertia can therefore be used as a training tool to improve swing speed in baseball athletes.

The third question that we answered was: The body temperature reaction to a high-intensity baseball swing warm-up program viewed with an infrared camera. This was very important because nobody had recorded the effect of a baseball warm-up on the skin. This project gave us an insight on the physiological response of the body during a baseball warm-up. We were able to get results that are in accordance with previously executed research on the correlation between warm-up intensity and the effect of skin temperature regulation. Our study showed that after executing a high-intensity warm-up, the skin temperature will decrease. The decrease in temperature was comparable in size to past research. More research is needed to confirm the findings, but our study can be used as a proof of concept. Further studies could determine if infrared imaging can be used to assess the quality of a warm-up.

What we understand from our studies using a dynamic moment of inertia bat is that the dynamic moment of inertia bat is superior to other warm-up tools that increase the swing resistance for multiple reasons. Since the dynamic moment of inertia bat has a variable weight, we can have the same weight for the normal bat and for the warm-up tool to negate the kinesthetic illusion. Something else that we need to make sure before recommending a warm-up tool or a training tool is the effect of the tool on the swing's biomechanics. A heavy bat changes bat kinematics and alter the swing trajectory. (Laughin et Al., 2016) The use of a heavy bat usually resulted in a reduction in linear velocity and an increase an angular displacement. Based on past studies, the use of a dynamic moment of inertia bat does not affect the swing mechanics compared to a heavier bat.

To summarize everything, we know that we need to practice swinging at a very high speed with a bat or device that replicates the moment of inertia of the normal bat that players will use to swing at-bat. If we train with a heavier bat weight, the swing speed will probably decrease when we use a normal bat because the body was trained and prepared to swing slower. To increase swing speed, we need to train speed specifically. To specifically train speed, the use of a dynamic moment of inertia is a great asset. The use of a dynamic moment of inertia bat was proven to replicate a high-intensity warm-up thanks to our study with the infrared camera. The dynamic moment of inertia bat was proven to be helpful as a warm-up tool to prepare the player and negate the kinesthetic illusion in both baseball and softball competitive athletes. The dynamic moment of inertia bat was proven to be able to improve the swing speed even more when it is coupled with a training program for at least 6 weeks.

We believe that devices that use a dynamic moment of inertia as a resistance can help to improve the swing speed. More questions are still unanswered and will need further testing. More research is needed to see how dynamic moment of inertia devices can apply to other swing sports such as tennis, hockey or golf.

Limitations to our studies

In the province of Quebec, the amount of high-level or professional baseball team is very limited. Our participants were part of the highest level accessible to athletes in the province of Quebec. Our study was limited by the population that was accessible to us for our project. We did not have access to a professional team.

The year 2020 was a pandemic year with the COVID-19 virus. This affected our study in many different ways. Our participants were not able to complete some our studies because research projects involving humans were prohibited. Concordia University was closed for a year and in-person attendance was limited. Once we got the green light to conduct human research, the province of Quebec was put into lockdown and the population had to avoid going out. The athletes could not participate in our studies at that time either.

We are happy with our results. We feel strongly about what we were able to accomplish. We are also very happy to have been able to involve young athletes in research as they are not involved in research projects very often.

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Appendices

Figure 4. This is a sketch of the prototype that is defined as the dynamic moment of inertia bat. The handle can be seen on the right-hand side, the removable weights are the orange disks and the elastics are the black tubes next to the removable weights.

Figure 5. A picture of the data measurement set-up. We can see distance markers on the floor to facilitate the calibration of the Kinovea software. We can see a participant holding his own bat just before he swings towards a ball on a tee. In a ladder, I was filming using a high-speed camera the swing of the participant. Extra lights had to be added to compensate for the darkness of the indoor field to allow use to see something on the high-speed footage. The ball is batted into a net as a safety measure.

Baseball strength training program

Tempo – rest: XX-YY-ZZ-YY-RR (in seconds)

XX: concentric - YY: isometric top or bottom - ZZ: eccentric - RR: rest

Week 1-2

Name	Sets	Reps	Weight	Tempo - rest
Jumping alternating lunges	2	10	BW	1-0-1-0-30
Tuck jumps	2	10	BW	1-0-1-0-30
Woodchoppers with med. Ball	2	10	10lbs	2-0-2-0-30
Standing trunk anti-rotation (pulley)	1	15 B	Var.	2-10-2-2-30
Reverse throwing (pulley)	1	15 B	Var.	3-0-2-0-30
Prone HS curl	4	5	Heavy	3-0-3-0-30
Medicine ball crunches throws	1	20	15lbs	2-0-2-0-30

Prototype bat training: 3x8 swings on each side

Week 3-4

Name	Sets	Reps	Weight	Tempo - rest
Kettlebell swings	2	10	Var.	2-0-2-0-30
Single leg hops sideways	2	10 B	BW	1-0-1-0-30
Med. Ball rolling push-up	2	8 B	Var.	2-0-2-0-30
Deadlift	1	15	Var.	4-0-4-0-60
Bench press	1	15	Var.	4-0-4-0-60

Standing SH ER/IR (pulley)	4	5	Var.	2-0-2-0-15
Medicine ball Russian twists	1	20	15lbs	2-0-2-0-30

Prototype bat training: 3x10 swings on each side

Week 5-6

Name	Sets	Reps	Weight	Tempo - rest
Burpees	4	8	BW	3-0-3-0-30
Glute bridge	2	15	Var.	1-0-4-0-30
Single leg hop	2	10 B	10lbs DB	1-0-1-0-15
Barbell hang clean	1	15	Var.	2-0-2-0-30
Nordic curl assisted	3	5	Var.	0-0-6-0-30
Sled/ weight drag	2	30 seconds	All-out	30-0-0-0-30
V-ups	2	10	BW	2-0-2-0-30

Prototype bat training: 3x15 swings on each side

Week 7-8

Name	Sets	Reps	Weight	Tempo - rest
Broad jumps	5	3	BW	1-0-1-0-30
Hip Thrusts	2	10	Heavy	1-0-4-0-30
Box jumps	5	3	All-out	1-0-1-0-15
Single arm DB hang clean	1	15 B	Var.	2-0-2-0-30
DB SH press	1	15 B	Var.	3-0-3-0-30
Nordic curl	4	5	BW	0-0-6-0-30
Side plank + hip ABD	1	20 B	15lbs	2-0-2-0-30

Week 9-10

Name	Sets	Reps	Weight	Tempo - rest
Jump squats	2	10	Var.	1-0-4-0-30
Reverse lunges	2	10	20lbs DB	3-0-3-0-30
Barbell hang snatch	2	10	Var.	1-0-0-0-30
Ecc. Bench press	4	4	Var.	1-0-8-0-30
SH lateral raise	1	15 B	Var.	2-0-3-0-30
Bicep curl	4	6 B	Var.	3-0-3-0-30
Elevated side plank isometric	2	20 seconds B	BW	2-0-2-0-30

Week 11-12

Name	Sets	Reps	Weight	Tempo - rest
Box jumps	2	10	All-out	1-0-1-0-30
Single arm DB single arm power snatch	2	10 B	Var.	1-0-0-0-30
Plyometric chest pass	2	10	10lbs	1-0-1-0-15
Ecc. Back squat	1	15	Var.	0-0-8-0-30
Fireman’s carry	2	15 steps	Var.	0-0-0-0-30
Single leg hops	4	5 B	Var.	1-0-1-0-30
Side jack-knives	1	20 B	BW	1-0-2-0-30

Form filled by baseball players after their swing warm-up in the lab before the second set of infrared pictures.

Modified RPE scale

After swinging the prototype, I feel that my swing speed will be:

1. Apparently slower
2. Slightly slower
3. Equal to standard bat
4. Slightly faster
5. Apparently faster

Additional comments:

Do you feel a positive effect on your body after warming-up with the prototype?

1. Yes
2. No

Name 2 things that you like about the device and how you feel it can help you

1.
2.

Is there anything we could change to the prototype to make it better in your opinion?

______

Grip strength

#1-

#2-

#3-