May 2023

Oxygen Consumption in Highly Skilled Baseball Pitchers

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OXYGEN CONSUMPTION IN HIGHLY SKILLED BASEBALL PITCHERS

By

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Bachelor of Science – Exercise Science
Utah Tech University
2020

A thesis submitted in partial fulfillment
of the requirements for the

Master of Science – Kinesiology

Department of Kinesiology and Nutrition Sciences
School of Integrated Health Science
The Graduate College

University of Nevada, Las Vegas
May 2023

Thesis Approval

The Graduate College
The University of Nevada, Las Vegas

April 10, 2023

This thesis prepared by

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entitled

Oxygen Consumption in Highly Skilled Baseball Pitchers

is approved in partial fulfillment of the requirements for the degree of

Master of Science – Kinesiology
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ABSTRACT

The purpose of this study was to describe the physiological demands of highly skilled baseball pitchers during pitching, along with pitch metrics. Three junior college and three professional (n = 6) baseball pitchers participated in this study. Participants completed a graded exercise test (GXT) to volitional exhaustion to determine maximal oxygen consumption (VO_2 max) and estimated body fat percentage, height, and body mass were measured on day one of testing. Next, participants faced live batters on a baseball field while wearing a portable metabolic analyzer (Cosmed K5) to measure respiratory gases including oxygen consumption (VO_2) and carbon dioxide produced (VCO_2) during pitching. During pitching, heart rate (HR) and pitch metrics, including pitch location, were recorded for every pitch using a pitch flight analyzer (TrackMan B1). Descriptive statistics for VO_2, percent VO_2 max (%VO_2 max), HR, percent HR max, and respiratory exchange ratio (RER) were reported across innings as well as across warmup, pitching, and rest intervals. A correlation analysis between physiological variables and performance variables was also conducted to determine if any relationship existed. During pitching intervals, the average %VO_2 max was 50.4 ± 6.6% (mean ± SD), average heart rate (HR) was 138.7 ±16.6 bpm, and the average RER was 0.79 ± 0.07. The %VO_2 max rose from 50.5 ± 6.17% in the first inning to 53.8 ± 11.28% in the second inning and then dropped to 48.6 ± 9.40% in the third inning. In order of inning pitched the RER values were 0.83 ± 0.06, 0.79 ± 0.05, and 0.75 ± 0.07. A statistically significant inverse relationship was observed between the average %VO_2 max during pitching intervals and strike percent for the entire trial ($r = -.864$, $p = .027$). This study suggests that pitchers who can perform at a lower percentage of their VO_2 max tend to have a higher strike percentage.

ACKNOWLEDGMENTS

The authors of this study acknowledge the support of the entire coaching staff at the College of Southern Nevada baseball team and all the players who agreed to participate in this study. The authors would also like to acknowledge the professional players who agreed to participate despite preparing for the upcoming professional season. No authors reported any conflict of interest in the study.

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CHAPTER 1 - INTRODUCTION

Baseball is a sport involving high intensity, full body movements that last for a very short duration. In 2022, prior to the introduction of the pitch clock, the average duration of a professional baseball game was three hours and three minutes, but each play was, on average, less than 10 seconds (Gough, 2022). An even shorter duration is observed during maximal effort pitching, with a reported duration of less than two seconds for the entire movement and a 0.156 second average span between plant foot contact and ball release while pitching (Stodden et al., 2008). The baseball pitching motion is a full body kinetic chain movement that requires the athlete to move in a coordinated but independent series of connected links. The pitching delivery utilizes the transfer of momentum from the large, lower limbs of the body to the smaller limbs of the upper body through sequential activation with the ultimate goal of producing ball velocity and accuracy. Successful pitching performance is an interplay between various biomechanical, psychological, and physiological variables.

To optimize training time off the field, baseball pitchers and coaches at highly competitive levels collaborate with strength and conditioning professionals. These professionals often address three primary goals: improving athletic performance, reducing injury occurrence, and teaching lifelong fitness and movement skills. These can be accomplished by using empirical evidence and practical experience to develop, implement, and maintain a strength and conditioning program. Training programs apply the principle of specificity (Baechle et al., 2008) and create training that mirrors the cardiorespiratory and energetic demands of the athlete's individual sport to transfer training effect and improve performance. The short duration, explosive nature of the pitching motion can be considered a primarily anaerobic activity. However, much of the information regarding the physiological demand and intensity of baseball pitching is anecdotal and lacks empirical evidence (Symanski, 2009; Potteiger, 1989; Gambetta, 1997).

Previous research has supported a relationship between cardiorespiratory fitness and pitching performance in professional baseball pitchers (Gillett et al., 2016). Increased aerobic capacity had statistically significant ($p < 0.001$) relationships with the number of wins and strikeouts pitchers had as well as their earned run average (Gillett et al., 2016). These findings indicate the need for developing aerobic training programs for pitchers and necessitates further research on the intensity of pitching. The physiological intensity of pitching has been examined previously by using the relationship between heart rate and oxygen uptake on 16 professional baseball players during live games (Cornell et al., 2017). Average heart rate was approximately 84% of maximal heart rate for all participants with noted differences depending on the location and inning of the game (Cornell et al., 2017). Several other studies have used this same relationship to examine demands during simulated and intra-squad games, which may not cause the same physiological response as a live game. Previously, only one study included the measurement of respiratory gas exchange concomitantly with heart rate during a simulated game in a laboratory setting to examine the physiological intensity of pitching (Potteiger et al., 1992). During pitching, the highest oxygen consumption of any participant expressed as a percentage of maximum oxygen consumption was only 45% (Potteiger et al., 1992). However, oxygen consumption was only collected and analyzed every two minutes throughout the simulated game, and this may limit the generalizability of the findings.

There is a need to generate empirical evidence for baseball pitching and physiology, as this data has been historically limited, in part due to limitations of appropriate measuring devices to collect physiological data, such as oxygen consumption, during the pitching motion. The recent development of innovative technology, like accurate portable metabolic systems, allows pitching physiology to now be studied in greater depth. Portable metabolic systems provide reliable measures (ICC 0.75-0.88, CV 3-8%) of respiratory gas exchange in sport specific settings outside the laboratory (White et al., 2019; Guidetti et al., 2018). Pitchers, coaches, and conditioning professionals would benefit from the knowledge of physiological demands and changes in oxygen consumption for a pitching performance across an entire game and how they may relate to performance variables like maintaining velocity and command. However, there is a general lack of information on the description of how physiological parameters vary during a pitching session. Therefore, the purpose of this study is to describe the physiological demands of highly skilled baseball pitchers during pitching, along with pitch metrics. This descriptive study is a necessary step to further develop hypothesis driven research.

CHAPTER 2 - LITERATURE REVIEW

The biomechanics of baseball pitching are a frequently studied topic with considerable empirical evidence currently (Dillman et al., 1993, Fleisig et al., 2009; Fleisig et al., 1999; Orishimo et al., 2022). Previous biomechanical research has developed a clear description of the kinematics, kinetics, and injury mechanisms for the baseball pitching motion. However, physiological aspects of pitching have considerably less research, with much of it investigating resistance training programs and their relation to performance variables (Syzmanski et al., 2010; Syzmanski, 2012). The relationship between pitching performance and cardiorespiratory fitness has also been previously described and compared across pitching roles for seven major league seasons (Gillett et al., 2016). Each season max oxygen consumption (VO_2 max) was measured, and peak oxygen consumption (VO_2 peak) and oxygen consumption at anaerobic threshold (AT) for 14 starting pitchers and 10 relief pitchers (n = 24) were estimated. Starting pitchers demonstrated a higher VO_2 max than relief pitchers at 49.49 ± 4.59 $ml \cdot kg^{-1} \cdot min^{-1}$ and 45.28 ± 5.72 ($t = 2.50$, $p < 0.01$) , respectively (Gillett et al., 2016). No differences were observed between relief and starting pitchers for anaerobic threshold. The VO_2 peak, for every pitcher, and the VO_2 max, for starting pitchers, demonstrated low-to-high relationships with several performance variables (table 1). These findings support that a higher VO_2 max appears to be related to several performance variables.

Table 1. Relationship between performance variables and physiological variables.

Performance Variable	**All Pitchers** VO_2 Peak	**Starting Pitchers** VO_2 Max
Wins	0.550**	0.548*
Strikeouts	0.572**	0.572**
Walks per 9 innings	-0.358*	-0.416*
Walks & Hits per inning	-0.484**	-0.685**
Strikeout per walk	0.602**	-
Homerun per 9 innings	-	-0.478*
Hits per 9 innings	-	-0.589**
Strikeouts per 9 innings	-	0.614**
Earned run average	-	-0.678**

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the < .001 level (2-tailed).

Studies not aimed at performance variables look to describe the physiological characteristics of baseball players and pitchers. Physiological characteristics that are commonly measured and described include muscular strength (expressed as repetition maxima), power, anaerobic capacity, aerobic capacity, maximum heart rate, and anthropometrics, including estimations of body composition. Average body fat percentage for professional baseball pitchers was estimated in two separate studies via skinfold calipers and reported a percentage of 13.6 ± 6.1 and 15.28 ± 3.45 (Coleman, 1982; Gillett et al., 2016). Comparable values for body fat percentage have been reported for collegiate baseball players in several other studies using bioelectrical impedance analysis with percentages ranging from 14-17% (Potteiger et al., 1992; Potteiger et al., 1992; Szymanski, Szymanski et al, 2010). The range of values for VO_2 max in baseball pitchers has been consistent across studies and across skill levels. Professional baseball players VO_2 max ranges from approximately 45-51 $ml \cdot kg^{-1} \cdot min^{-1}$ while collegiate players have a larger range from 45-55 $ml \cdot kg^{-1} \cdot min^{-1}$ on average (Coleman, 1982; Potteiger et al., 1992;

Potteiger et al., 1992; Gillett et al.; 2016). These values reflect the physiological attributes of baseball pitchers but minimal research that contributes directly to the understanding of the physiological demands and intensity during pitching exists.

The intensity of baseball pitching has been addressed anecdotally by researchers, coaches, and strength and conditioning professionals (Symanski, 2009; Potteiger, 1989; Gambetta, 1997; Rhea & Bunker, 2009; Watkinson, 1998; DeRenne, 1990). Experts widely agree that baseball pitching is a task that relies primarily on anaerobic metabolism for energy supply. Meaning, energy in the form of adenosine triphosphate (ATP) must be present in the muscle for contraction to occur, and the process of ATP production depends widely on the duration and intensity of the task. Pitching intensity is a maximum, or near maximum, effort that lasts less than two seconds and, depending on the pitcher's age, role, and efficiency, can be repeated upwards of 100 times within a single game. Regardless of the number of repetitions, extended game times may still accentuate the importance of anaerobic capacity and power over the aerobic capacity of pitchers (Potteiger et. al, 1989; Rhea & Bunker, 2009). Aerobic capacity has been addressed and emphasized by a few experts within the industry (Syzmanski, 2009; DeRenne; 1990; Cimino, 1987; House, 1996; Coleman & Coleman, 2000) but coaches and teams still vary in their conditioning practices. To identify common practices among major league baseball (MLB) strength and conditioning (S&C) coaches, researchers sent out surveys to all 30 MLB teams (Ebben et al., 2005). Seventy percent (21 of the 30) of MLB teams responded to the eight-section survey inquiring on flexibility development, speed development, strength/power development, plyometrics, and fitness testing. The most common fitness tests performed were body composition (10 out of 21), anaerobic capacity (9 out of 21), muscular strength (7 out of 21), and muscular power (7 out of 21). Cardiovascular endurance testing was only performed by

5 of the 21 teams using a couple of different running protocols. The surveys also revealed that all 21 MLB S&C coaches incorporated speed development into their teams' programs, and 20 of the S&C coaches included plyometrics in training. These findings, in combination with anecdotal publications, indicate that training for baseball pitchers is currently focused on developing speed, power, and anaerobic capacity.

A key principle for all training programs is the concept of specificity. Specificity in training involves mirroring the physiological requirements of that sport to prepare the athlete and minimize injury occurrence. Few studies have examined the effects of different resistance training and conditioning methods, and how they affect baseball specific performance variables (Rhea et al., 2008; Potteiger et al., 1992; Syzmanski, 2012). A common performance variable measured in baseball players is lower body power during various jumping protocols due to the movements having similar durations and being explosive in nature. These explosive moves and their measured ground reaction forces can be used to calculate power output and assess fatigue, measure level of preparedness, and track training adaptations throughout training programs (Rhea et al., 2008; Dodd & Alvar, 2007; Stone & Schilling, 2020). One training study examined two different conditioning programs on 16 division-one baseball players and their effects on lower body power (Rhea et al., 2008). Lower body power was measured before and after an 18-week baseball season with both groups performing conditioning 3-4 times a week and resistance training 2-3 days a week. The resistance training program was the same for both groups, while the sprint group (n=8) performed repeated maximal effort sprints lasting 10-60 seconds for conditioning and the endurance group (n=8) performed moderate-to-high intensity cycling or jogging. The endurance group experienced a 39.50 ± 128.03 decrease in Watts while the sprint group increased power output by 210.63 ±168.96 Watts. There was a significant difference in the change of power output between groups ($p < 0.05$) and pre-test and post-test values were significantly different for the sprint group ($p < 0.05$). The large variation between participants is of particular interest and may point to the variation in individual response to training. Further examination of power output at the individual level showed that all but 3 of the endurance group participants showed a decrease in power, while all sprint group participants increased power output. Any decrease in power output can have a detrimental impact on baseball performance and this may indicate a need to favor anaerobic training.

Anaerobic and aerobic training groups were assigned in a similar study to investigate the effects of conditioning on estimated body composition, cardiorespiratory fitness, and baseball related variables (Potteiger et al., 1992). The baseball related variables included flexibility, vertical jump, anaerobic power, throwing velocity, and 30-yard dash time for 21 male NAIA collegiate baseball players. Players were randomly assigned to either the weight/sprint group or the aerobic dance group, and both groups trained 4 times a week with each session lasting one hour. During the hour, the aerobic dance group performed dancing and calisthenic exercises led by an instructor at an intensity of 60-90% of their heart rate reserve. The weight/sprint group began with eight exercises for three sets of 8-12 repetitions on every exercise and finished with sprint training. The sprint training consisted of six total sprints with 30 seconds of rest in between each sprint and all sprints lasted 10 seconds, with only three of the sprints being at max effort. The aerobic dance group saw statistically significant ($p \leq 0.05$) decreases in estimated body fat percentage from pre to post test (15.2 ± 2.4 and 13.9 ± 2.9, respectively) while the sprint group did not. Neither group saw a statistically significant improvement in any of the cardiorespiratory fitness measures. The weight/sprint group had statistically significant improvements ($p \leq 0.05$) with small (0.2) effect sizes (Hopkins, 2006) in several baseball related parameters including flexibility (30.4 ± 8.0 cm to 33.4 ± 7.6 cm, *d* = 0.38), vertical jump height (54.2 ± 6.9 cm to 56.8 ± 5.3, *d* = 0.42), anaerobic power (132.6 ± 19.0 kg/min to 128.4 ± 15.7, *d* = 0.24) and throwing velocity (74.8 ± 5.0 mph to 77.1 ± 3.8, *d* = 0.52). The aerobic dance group was not significantly different in any of the baseball specific parameters. Both training studies provide support for the currently accepted belief that maximal effort baseball throwing is primarily an anaerobic activity. This warrants further examination into the intensity of physiological demands of real time baseball pitching.

One method of measuring physiological intensity of a physical activity is by measuring heart rate and articulating it as a percentage of maximal heart rate. Heart rate (HR) has a direct relationship to oxygen uptake which helps characterize the intensity of a task (Achten & Jeukendrup, 2003). Describing intensity of baseball pitching via heart rate has been done several times producing varying results (Cornell et al., 2017, Potteiger et al., 1992). Many of these studies were performed in a laboratory setting or during simulated game which may cause the results to differ from in-game responses. In-game heart rate responses in 16 minor league baseball players across an entire season showed some of the limitations to this method of measuring intensity (Cornell et al., 2017). Heart rate was captured with a wireless HR monitor following the completion of all warm-up activities and until the pitcher was finished with their respective outing or removed from the game. Intensity was expressed as a percentage of each participants estimated maximal HR (220-age) and a total of 632 innings were included in the results. The mean maximal HR percentage for the group across all innings was 84.8 ± 3.9% and post hoc analysis revealed maximal HR was significantly different for location of the game and the inning ($F_{5,294} = 10.245$, $p < 0.001$, $\eta^2 = 0.202$). During the first and second inning of home games maximal HR was significantly higher ($p \leq 0.05$) than all other innings. As well, the percent HR in the first inning significantly greater than the second (87.3 ± 3.6% and 85.0 ± 3.4%, respectively). The changes in heart rate based on location and inning may represent psychological responses to the game indicating a higher perceived stress which may confound the findings regarding physiological intensity. Intensity, as indicated by HR, was notably higher in this study than previous studies done in laboratory and simulated game settings indicating those settings may underestimate the physiological responses to baseball pitching. This study also contributes to the notion that pitching in-game tends to be primarily anaerobic in nature, but limitations in the indirect measure of intensity are likely present due to psychological aspects of competition.

To create a detailed description of the physiological demands of pitching, it would be appropriate to measure HR concomitantly with respiratory gas exchange data. Oxygen consumption, heart rate, and blood lactate concentrations have been previously examined with measurements occurring before, during, and after pitching for six male collegiate pitchers during a simulated game (Potteiger et al., 1992). The simulated game protocol aimed to mimic game-like situations as much as possible and included 14 pitch innings, six-minute rest intervals (to simulate between innings), and a total of 98 pitches thrown near maximal effort. Effort was maintained by measuring velocity with a radar gun and confirming pitchers' velocity was within 95% or more of their previously recorded velocity. Prior to throwing the participants also performed a graded maximal treadmill test using open circuit spirometry to determine VO_2 max. Respiratory gases were collected and analyzed every two minutes during the protocol and for the entirety of the game. The total amount of oxygen consumed was determined and the respiratory exchange ratio (RER), energy cost per minute, and total energy expenditure were then calculated. The mean total oxygen consumed for participants was 44.5 liters and total energy expenditure was calculated at 227 kilocalories (kcal) or 2.7 kcal per minute. When expressed as a function of VO_2 max (mean VO_2 max = 45.8 $ml \cdot kg^{-1} \cdot min^{-1}$) the highest value found for any of the six participants was equal to 45% of VO_2 max during the inning. During the rest interval between innings the value dropped to slightly above 10% of VO_2 max. The mean RER during simulated innings was 0.94 and increased to 0.97 during the six-minute rest interval between innings. As the innings progressed a significant quadratic effect was observed in HR with a 10% increase (from 133 -147 bpm) from inning one to five and a mean HR of 140 beats per minute for the entire game. The heart rate values in this study were lower than other similar studies which may be attributed to the lack of a hitter during pitching combined with researchers limiting the rate of pitches thrown (1 pitch per 20 seconds). Another fault in this study was measuring and analyzing respiratory gases every two minutes throughout the duration of study protocol, which may not provide all the necessary information to determine true physiological demands of pitching. Pitching physiology can now be studied further due to the development of innovative technology like portable metabolic analyzers.

Most exercise physiology labs aiming to analyze respiratory gas exchange do so with a stationary metabolic cart. However, wearable metabolic analyzers allow for carbon dioxide production, substrate oxidation, and oxygen uptake to be determined outside of the laboratory. Field devices must be lightweight so they can easily travel with athletes or participants and do not disrupt their natural movement pattern or effort level. Measurements taken during competition-like circumstances may allow for a more specific description of the activity compared to laboratory protocols, given the measuring device is reliable and valid. Several studies have compared the reliability and accuracy of portable metabolic analyzers with several types of stationary metabolic carts to support their use for research purposes (Perez-Suarez et al., 2018; Crouter et al., 2019; Guidetti et al., 2018; White et al., 2019). Respiratory gases of 15 participants collected with the Douglas bag method and a portable metabolic system (Cosmed K5) showed good agreement over a during a wide range of cycling intensities. The portable system was within 2.1 liters per minute (l/min) for minute ventilation and 0.08 l/min for oxygen consumption and was not significantly different from the Douglas Bag methods ($p \geq 0.05$) (Crouter et al., 2019). During work periods at higher intensities, the portable unit significantly underestimated carbon dioxide production and overestimated it during rest periods (0.05 l/min, $p = 0.006$, and 0.31 l min, $p < 0.05$, respectively). One study comparing two portable analyzers found that if the aim of the investigation was to measure oxygen consumption or substrate oxidation at higher intensities, the mixing chamber setting on the Cosmed K5 was preferable. The K5 also showed excellent reliability during field tests with total energy expenditure values for repeated measures, having a coefficient of variation of 4.5% with a confidence interval of 3.2-6.9% and a correlation coefficient of 0.91 (Perez-Suarez et al., 2018). The findings in these articles suggest that a portable metabolic analyzer is a reasonably reliable and accurate device for field testing of respiratory gas exchange during pitching.

Physiological data that examines the energy requirements, substrate utilization, and physiological response to baseball pitching while facing batters is very limited. Pitching performance has been shown to have a relationship with measures of aerobic capacity even though throws are performed with near maximal effort (Gillett et al., 2016). Pitching is generally considered as being high-intensity activity that relies heavily on energy systems that produce ATP without the presence of oxygen and experts rarely discuss the needs for aerobic conditioning. Aerobic capacity may not be a limiting factor in pitching due to adequate recovery times in-between throws and endurance training may have a deleterious impact on lower body power in pitchers. However, power output may be increased by performing anaerobic conditioning and have a positive influence on certain baseball performance variables. Improving performance is a primary concern for coaches, players, and S&C professionals, and optimal conditioning practices have yet to be supported by empirical evidence. Only two studies have attempted to describe intensity during pitching and only one included a metabolic cart to provide insight into respiratory gases (Cornell et al., 2017, Potteiger et al., 1992). Measures of oxygen consumption, expired gases, and respiratory exchange ratio while throwing to batters would help approximate the specific physiological requirements of pitching and aid in the development of conditioning programs. This is now possible with the development of portable metabolic systems that can be worn during the pitching motion and can bridge a current gap in the literature.

CHAPTER 3 - METHODS

Participants

Six baseball pitchers across three different playing levels were recruited to participate in this study as part of a convenience sample. The mean and standard deviation for height, mass, and age for all participants was 187 ± 4 centimeters, 88.0 ± 10.6 kilograms, and 21 ± 2 years, respectively. Participants were screened prior to any testing by providing participants with a printed PARQ and ACSM screening document. Additionally, none of the participants reported any musculoskeletal injuries that would interfere with their ability to pitch at maximal effort. Three participants were recruited from a junior college (JUCO) baseball team, and 3 participants were recruited from a training facility that accommodates professional (PRO) baseball pitchers. This study took place during the pitcher's pre-season and all data were collected while facing hitters. This study was approved by the institutional review board (IRB#: 2022-566) of the University of Nevada, Las Vegas and all participants provided written informed consent before any data were collected.

Procedures

Data collection occurred over two separate days for all participants with test days separated by at least 48 hours and at most four weeks. On the first day, participants reported to the lab and anthropometrics were measured, and body composition was estimated using direct segmental bioelectrical impedance (InBody 770, InBody USA, CA, USA). Following all measures of anthropometrics, participants were fitted with a chest strap to measure heart rate (Polar H9, Kempele, Finland) and were allowed time to warm-up on the treadmill (Woodway 4Front, Woodway USA, USA). Following the self-selected warm-up, participants were fitted for a mask to breathe into a portable metabolic analyzer (Cosmed K5 Metabolic System, Rome, Italy). Participants were asked to perform a maximal graded exercise test (GXT) using a modified Costill/Fox treadmill protocol to determine the maximal amount of oxygen they consume (VO_2 max) during intense exercise. The modified Costill/Fox protocol has been supported as a valid and time efficient way to measure physiological response in both rained and untrained individuals (Kang et al., 2001). Early stages of the GXT were four-minutes in length with only increases in speed at the end of each stage until participants reached an RPE of 13. Speed remained constant for the rest of the test and a two percent grade increase was administered every two minutes until the end of the test. The test was terminated when participants reached volitional fatigue.

The second day of collection took place on a local baseball field with major league baseball dimensions. Participants completed all their respective warm-up activities prior to any collection. Once participants were ready to begin throwing at maximal effort, they were fitted with the chest strap to measure heart rate (HR) and portable metabolic system with mask to measure respiratory gases. Participants completed 5-10 warm-up throws to familiarize themselves with throwing with a mask on then collection began. Participants faced lived hitters while wearing all collection devices.

Gases (i.e., $VO_{2'}$ VCO_2) were sampled every 10 seconds for the duration of the collection, which consisted of completing three innings or a maximum of 50 pitches. To ensure the safety of all participants, pitchers threw from behind a protective screen (Figure 1) in the case of a ball hit back in play directly towards them. Attached to the screen was an apparatus that allowed for the portable metabolic analyzer to travel with the pitchers on the mound. This way the pack was not worn directly on the back/shoulders and minimized any disturbances to the natural pitching delivery of the participants.

Pitched ball velocity and location were measured by a pitch flight analyzer (TrackMan B1, TrackMan Scottsdale, AZ, USA). Pitch location was measured to provide an objective measure of pitch accuracy and was gathered simultaneously with all physiological data. Data collection was terminated two minutes after the last pitch was thrown.

Figure 1. *Protective Screen and Apparatus Setup for Data Collection.*

Data Reduction

The data from all GXT tests were exported and the VO_2 max was calculated as the average amount of oxygen consumed over the last minute of the test. The pitching session was separated into warm-up, pitching (working), and rest intervals. Additionally, pitching intervals were further broken down into individual innings and pitch characteristic data were added to the file for examination. For every interval, heart rate (HR) data were collected and the average and maximum value for the specified interval was reported. Raw data for oxygen consumption (VO_2) and carbon dioxide produced (VCO_2) were originally reported in milliliters per minute (ml/min). The VO_2 data were first converted into units of milliliters per kilogram per minute ($ml \cdot kg^{-1} \cdot min^{-1}$) to represent relative oxygen consumed (relative VO_2) and then normalized to VO_2 max (%VO_2 max). Pitching VO_2 was defined as the average VO_2 during pitching intervals using units of $ml \cdot kg^{-1} \cdot min^{-1}$ and Pitching %VO_2 was defined as the average VO_2 normalized to VO_2 max. Next, the respiratory exchange ratio (RER) was calculated by dividing the VCO_2 by the amount of VO_2. Lastly, total energy expenditure was determined by averaging the reported energy expenditure per minute (kcal/min) for the entire trial and then multiplying by the total amount of time collected in minutes. The velocity and accuracy of every pitch was tracked and reported in the same file as the metabolic data previously described. The average velocity of all fastballs thrown was calculated and the maximum fastball velocity (FB velo) for the entire game was also reported. The velocity of all other pitches thrown was not included due to the intent of these pitches not always being maximal and on average 60% (28 ± 6) of the pitches thrown were fastballs. Accuracy was determined by calculating the strike percentage (K%) by dividing the number of strikes thrown by the total number of pitches thrown within the specified interval (inning or game). Any pitch that was put in play or contacted the bat of the hitter was considered a strike as well.

Statistical Analysis

Descriptive statistics for all anthropometric and cardiorespiratory fitness data (height, weight, age, body composition, and VO_2 max) will be presented. Likewise, descriptive statistics of HR, VO_2, %VO_2 max, and RER will be presented for warm-up, each inning, as well as each interval between innings. Finally, energy expenditure per minute (kcal/min), and total energy expenditure will be provided for every participant and across the entire trial.

A correlation analysis between physiological variables and performance variables (FB velocity & K%) was also conducted to determine if any relationship existed. All statistical analysis was performed in SPSS statistics version 28 (SPSS, Armonk, NY, USA). Correlations values were considered very strong/large between 0.70-0.90, strong/large between 0.50-0.70, moderate/medium at 0.30-0.50, and low/small at less than 0.30 (Hopkins, 2006) . Statistical significance was set at an alpha level of 0.05 ($p < 0.05$) and all data were expressed as means and standard deviations.

CHAPTER 4 - RESULTS

For all participants, VO_2 max was 47.7 ± 3.0 $ml \cdot kg^{-1} \cdot min^{-1}$ and estimated percent body fat was 9.7 ± 3.3% (Table 2). Descriptive data for all the physiological variables across the entire pitching, warmup, and rest intervals is presented int table 3. During pitching intervals, the average %VO_2 max was 50.4 ± 6.6%, average heart rate (HR) was 139 ±17 bpm, and the average RER was 0.79 ± 0.07. The values for %VO_2 max and HR were noticeably lower (32.7 ± 7.1% and 131 ±13 bpm, respectively) during resting intervals while the RER value was higher (0.83 ± 0.07). At resting intervals, the %VO_2 max and HR fell to 23.3 ± 3.3% and 102.8 ±10.0 bpm, respectively and the RER climbed to 0.88 ± 0.07. The average energy expenditure across the entire pitching trial was 272.8 ± 66.2 kcal.

An inning-by-inning description is provided in table 4. A downward trend in HR, percent HR max (%HR Max), and RER can be seen as the pitcher's progress further into the trial (figure 2). Average %HR max for inning one, two, and three was 74.0 ± 10.1%, 71.9 ± 8.1%, and 69.3 ± 8.2%, respectively. In order of inning pitched the RER values were 0.83 ± 0.06, 0.79 ± 0.05, and 0.75 ± 0.07. A different trend was observed in relative VO_2 and %VO_2 max with values increasing from inning one to inning two and then falling below inning one values for the third and final inning (figure 2). The %VO_2 max rose from 50.5 ± 6.2% in the first inning to 53.8 ± 11.3% in the second inning and then dropped to 48.6 ± 9.4% in the third inning.

Table 2. Anthropometric data for all participants.

Participant	Competitive Level	Age	Weight (kg)	Height (cm)	Body Fat (%)	VO_2 max ($ml \cdot kg^{-1} \cdot min^{-1}$)
1	JUCO	19	82.7	182.8	7.5	49.7
2	JUCO	21	76.4	187.9	7.5	49.6
3	JUCO	19	91.7	190.6	9.3	47.0
4	PRO	25	86.7	186.4	7.5	51.2
5	PRO	25	107.2	183.6	16.0	45.9
6	PRO	22	83.5	194.6	10.6	43.1
	Mean	**21.8**	**88.0**	**187.7**	**9.7**	**47.7**
	SD	**2.7**	**10.6**	**4.4**	**3.3**	**3.0**

Table 3. Physiological variables across warmup, pitching, and rest intervals.

Variable	Interval					
	Warmup		Pitching		Rest	
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	16.7	± 3.61	24.0	± 3.2	11.0	± 1.3
Percent VO_2 Max	32.7	± 7.13	50.4	± 6.6	23.3	± 3.3
Heart Rate (bpm)	131.0	± 13.0	138.7	± 16.6	102.8	± 10.0
Percent HR max	67.8	± 6.93	72.5	± 9.3	53.6	± 6.2
RER	0.83	± 0.07	0.79	± 0.07	0.88	± 0.07

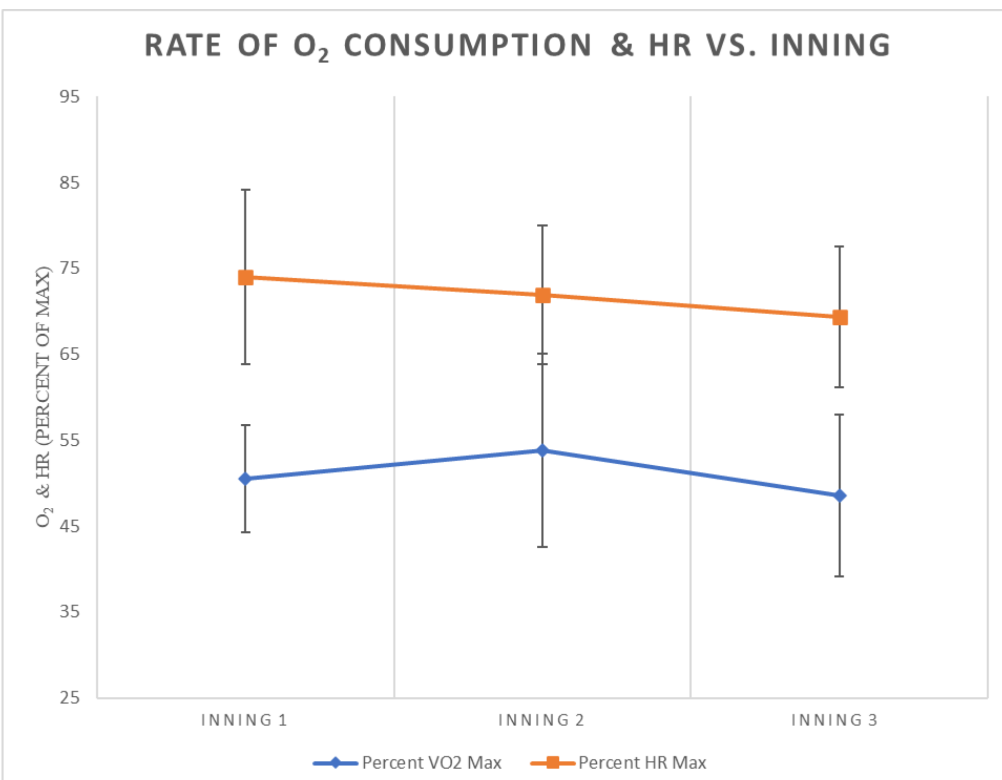
All data are presented as means and standard deviations of the average values across the entire respective interval

Table 4. Physiological variables across innings.

Variable	Inning					
	1st		**2nd**		**3rd**	
VO_2 (ml·kg^{-1}·min$^{-1)}$	24.1	± 3.1	24.4	± 3.3	23.1	± 4.5
Percent VO_2 Max	50.5	± 6.2	53.8	± 11.3	48.6	± 9.4
Heart Rate (bpm)	142.5	± 17.1	137.1	± 15.0	135.2	± 19.4
Percent HR max	74.0	± 10.1	71.9	± 8.1	69.3	± 8.2
RER	0.83	± 0.06	0.79	± 0.05	0.75	± 0.07

All data are presented as means and standard deviations of the average values across the entire respective interval

Figure 2. *Percent VO_2 Max and Percent HR max Across Innings.*



The descriptive data on the pitch metrics for all six participants showed an average of 46 ± 8.5 pitches thrown with a wide range of fastball velocities reported. Average fastball velocity for all participants in the study was 37.6 ± 2.4 m/s (84.1 ± 5.3 mph) and the average maximum fastball velocity was 38.8 ± 2.3 m/s (86.7 ± 5.1 mph). The highest velocity achieved by any of the participants was 41.1 m/s (92 mph) and the lowest maximum velocity was 35.3 m/s (79 mph). The average strike percentage for all participants was 52.5 ± 15.4% with a wide range also demonstrated for this variable (30.0 – 70.0%). A visual representation of the heart rate response and %VO_2 max values across an entire trial for each participant with respect to time can be seen in figures 3-8.

Prior to the correlation analysis, all the variables passed the assumption of normality using the Shapiro-Wilk method and an outlier was identified for %VO_2 max during rest for participant number six but the data point was not influential and was not involved in any statistically significant relationships. Analysis was presumed using the parametric analysis even though a single outlier was identified, and all data were included.

Figure 3. *Percent VO2 Max and HR Max Trends Across Entire Trial for Participant 1.*

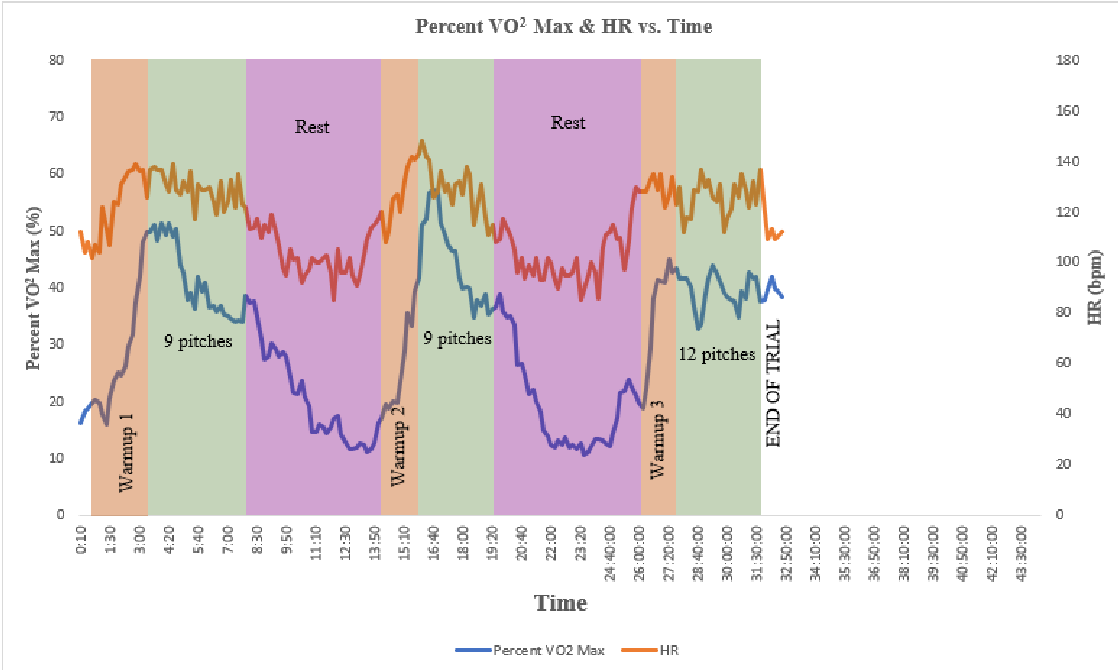


Figure 4. *Percent VO2 Max and HR Max Trends Across Entire Trial for Participant 2.*

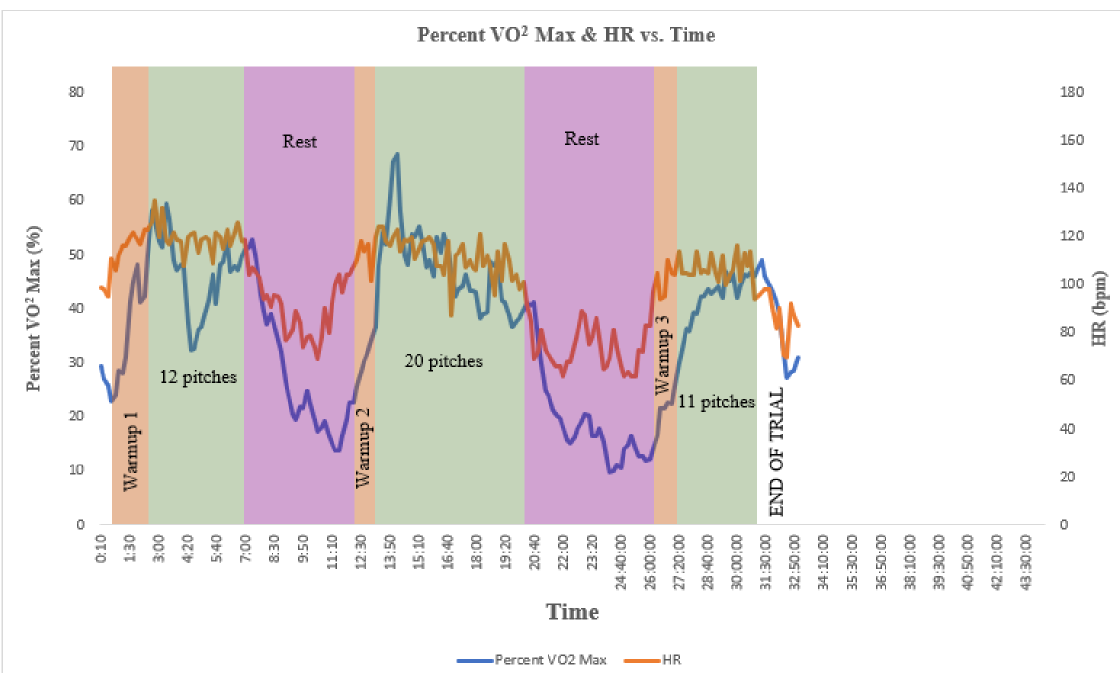


Figure 5. Percent VO2 Max and HR Max Trends Across Entire Trial for Participant 3.

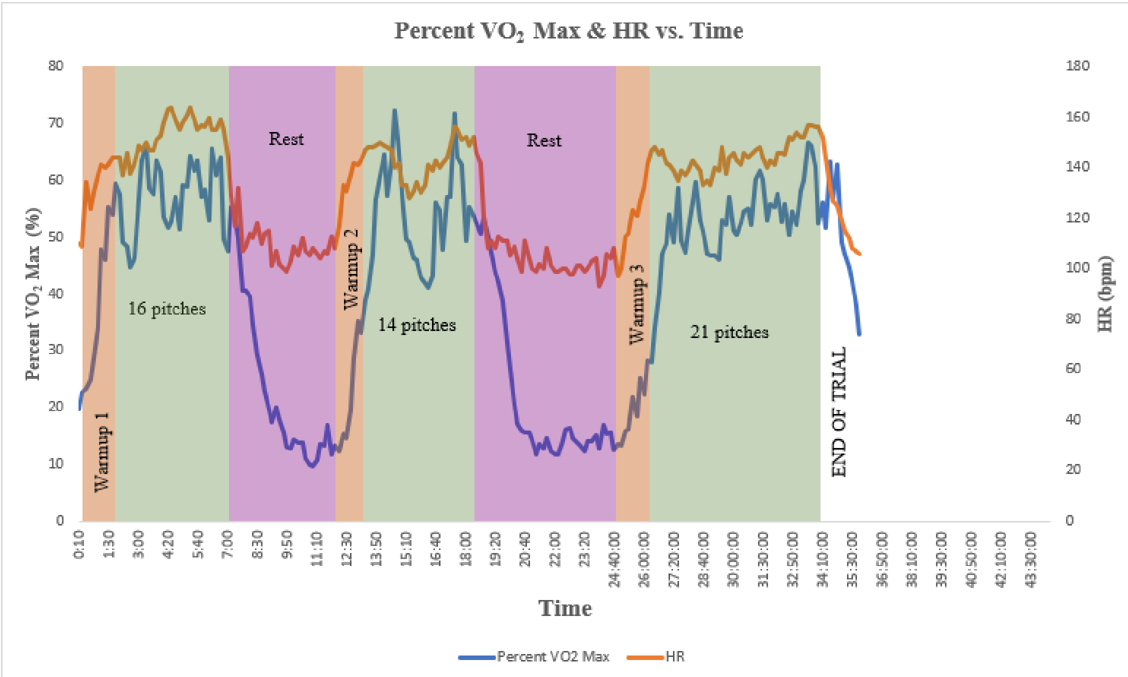


Figure 6. Percent VO2 Max and HR Max Trends Across Entire Trial for Participant 4.

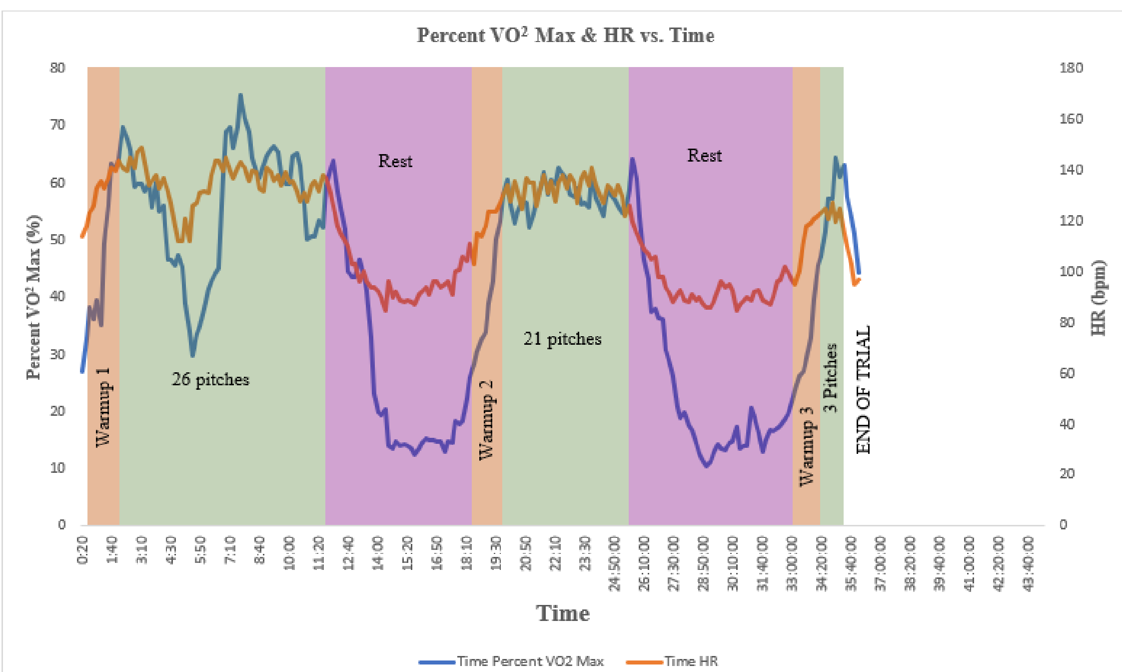


Figure 7. *Percent VO2 Max and HR Max Trends Across Entire Trial for Participant 5.*

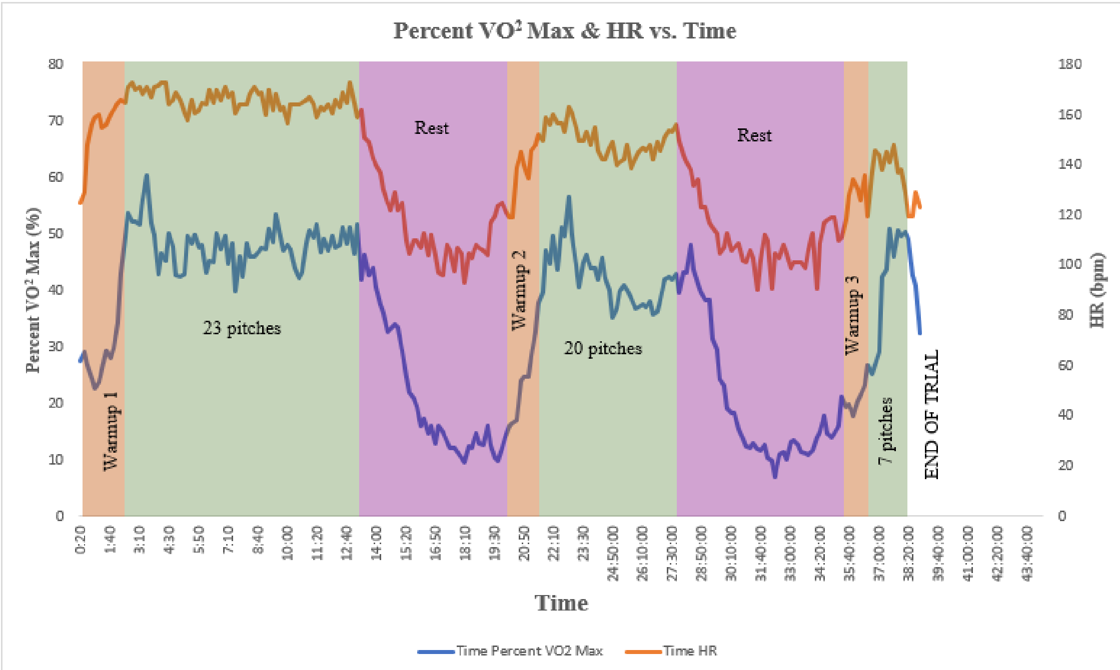
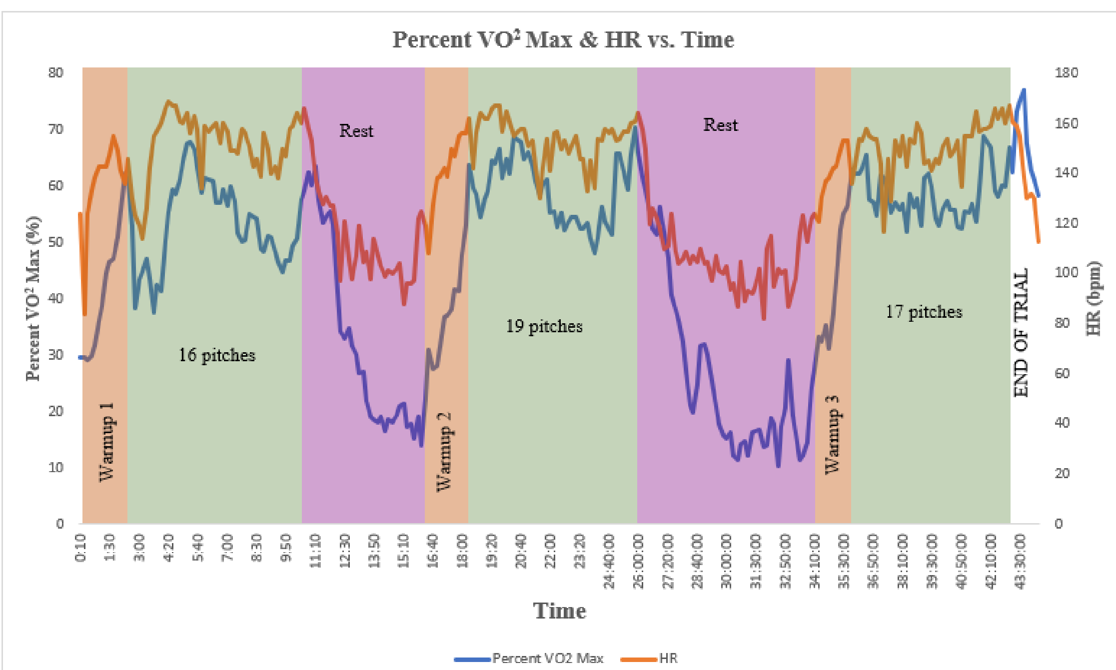


Figure 8. *Percent VO2 Max and HR Max Trends Across Entire Trial for Participant 6.*



An inverse relationship was observed between the average $\%VO_2$ max during pitching intervals and strike percent for the entire trial ($r = -.864$, $p = .027$, $r^2 = 0.746$). No other statistically significant relationships between physiological variables and performance variables were identified. VO_2 values during pitching and at rest had positive linear relationships with the $\%VO_2$ max values during pitching and rest ($r = .874$, $p = .023$, $r^2 = 0.764$ and $r = .852$, $p = .031$, $r^2 = 0.726$, respectively). Additionally, maximum fastball velocity had a positive relationship with average fastball velocity ($r = .990$, $p <.001$). Interestingly, there was no relationship observed between either resting VO_2 values (VO_2 or $\%VO_2$) and pitching performance but this is likely due to a narrow range of magnitudes (~ 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$) between subjects during rest. All the examined relationships are presented in table 5 and plots for statistically significant relationships can be found in the appendix (Figures 9-12).

Table 5. Correlation table for physiological and performance variables.

	VO_2 Max	Pitching VO_2	Resting VO_2	Pitching % VO_2	Resting % VO_2	Avg. FB Velocity	Max FB Velocity	Strike Percent
VO_2 Max								
Pitching VO_2	r = .249 p = .635							
Resting VO_2	r = .032 p = .951	r = .646 p = .166						
Pitching % VO_2	r = -0.251 p = .631	r = .874* p = .023	r = .654 p = .159					
Resting % VO_2	r = -.492 p = .321	r = .412 p = .417	r = .852* p = .031	r = .680 p = .137				
Avg. FB Velocity	r = -.566 p = .242	r = .321 p = .535	r = -.094 p = .859	r = .575 p = .233	r = .197 p = .709			
Max FB Velocity	r = -.651 p = .161	r = .206 p = .696	r = -.128 p = .810	r = .504 p = .308	r = .215 p = .682	r = .990** p = <.001		
Strike Percent	r = .164 p = .757	r = -.798 p = .057	r = - .506 p = .305	r = -.864* p = .027	r = -.510 p = .302	r = -.746 p = .089	r = -.684 p = .134	

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the < .001 level (2-tailed).

CHAPTER 5 - DISCUSSION

The purpose of this study was to describe the physiological demands of pitching in highly skilled baseball pitchers together with pitch metrics while competing against hitters. Physiological parameters of HR, VO_2, and VCO_2 were successfully measured with the latest portable metabolic technology simultaneously with pitch metrics across warmup, live pitching, and rest intervals. The measured $\%VO_2$ max during warmup intervals was 16.4 ± 3.6% and rose to 50.4 ± 6.6% during pitching intervals before falling to 11.0 ± 1.3% at rest. During pitching intervals RER was 0.79 ± 0.07 and rose to 0.83 ± 0.07 and 0.88 ± 0.07 during warmup and rest intervals, respectively. Participants HR was 139 ± 17 bpm during pitching intervals which equated to 73 ± 9% of their max heart rate reached during the GXT. Measures of VO_2 and $\%VO_{2\,max}$ were consistent across innings (F = 2.21, p = 0.160) while %HR max and RER showed a down trend but were also not different across innings (F = 3.05, p = 0.09 and F = 6.51, p = 0.51, respectively). A very strong/large inverse relationship between % VO_2 max during pitching and strike percent was noted (r = -.864, p = .027, r^2 = 0.746).

The majority of the measured and estimated anthropometric data reported in this study fall within the same ranges as previously reported by research (Coleman, 1982, Potteiger et al., 1992; Potteiger et al., 1992; Szymanski, Szymanski et al, 2010, Gillett et al.; 2016). The calculated VO_2 max of 47.7 ± 3.0 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ is on the lower end of the previously reported values with the highest estimated VO_2 max for any of the participants in the current study being 51.2 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ and the lowest estimated VO_2 max at 43.1 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$. The age (22 ± 3 years), height (187 ± 4 cm), and weight (88.0 ± 10.6 kg) are all within the commonly reported ranges as well. However, the estimated body fat percentage in the current study (9.7 ± 3.3%) is 4-7% lower than all other previously reported values.

The pitching %VO_2 max data may indicate that aerobic capacity is not a rate limiting factor in baseball pitching. Previous research reported oxygen consumption to be at 45% of the VO_2 max during pitching (Potteiger et al., 1992) while the current study indicates a higher value of 50.4 ± 6.6% during pitching. Additionally, Potteiger et al. (1992) reported a mean VO_2 max of 45.8 $ml \cdot kg^{-1} \cdot min^{-1}$ accounting for some of the differences in reported %VO_2 max values. The highest pitching VO_2 of 20.6 $ml \cdot kg^{-1} \cdot min^{-1}$ previously reported in the study was also lower than the pitching VO_2 during pitching intervals found in the present study, which was 24.0 ± 3.2 $ml \cdot kg^{-1} \cdot min^{-1}$. Resting %$VO_2$ values reported by Potteiger et al. (1992) were 10% of the max and in the current study it was observed that %VO_2 values were 23.3 ± 3.3% of the VO_2. Differences in these values are likely due to differing sampling frequencies and methodology. In the previous study, oxygen consumption was collected and sampled at two-minute intervals and in the present study, gases were continuously sampled every 10 seconds for the entire trial. Another interesting note for comparison between the current study and the one conducted by Potteiger et al. (1992) is the total energy expenditure across 7 simulated innings was 227 kilocalories (kcal) while the energy expenditure for the current study was calculated at 273 ± 66 kcals for three innings while facing hitters.

An average RER value of 0.79 for all working intervals suggests that baseball pitching primarily relies on fats as the primary substrate for energy production. An RER value of 0.79 translates to approximately 70% of the ATP production is being derived from fats while 28% is coming from carbohydrates. An increase in RER from pitching intervals to rest intervals was observed with an average RER during rest at 0.88. This increase in RER is likely due to an increase in ventilation or carbon dioxide production directly following exercise intervals. This same phenomenon was reported in previous research (Potteiger et al., 1992), with RER values during pitching intervals between 0.91-0.94 and rising to 0.97-1.11 during resting intervals. The increase in RER during resting intervals may indicate an increased reliance on carbohydrates to replenish ATP stores and return physiological responses to a baseline or resting level. It is challenging to determine the exact contribution of macronutrients to energy production because RER is most accurate during steady-state exercise (Goedecke et al., 2000). While there are many factors that affect the proportion of macronutrient contribution during exercise, the primary determinant is intensity (Ramadoss et al., 2022).

When examining heart rate in beats per minute, the data collected in the current study falls within the typically reported ranges for studies examining intrasquad and laboratory settings (Achten & Jeukendrup, 2003, Cornell et al., 2017, Potteiger et al., 1992). The average HR for the current study was 139 ± 17 bpm which equated to a %HR max of 72.5 ± 9.3%. The %HR max in the current study is lower than what Cornell at al. (2017) reported with the average %HR max for their sample being calculated at 84.8 ± 3.9%. Cornell et el. (2017) determined max heart by using the equation 220-age, whereas the current study used the measured maximum heart rate during the GXT which will account for some of the differences. Additionally, the data presented by Cornell et al. (2017) was in-game data collected during competition at the professional level and data in the current study was gathered while facing hitters, but not in a game scenario. In a competitive game, pitchers would also be required to respond to the outcome of the current hitter they were facing, including fielding and backing up bases, but due to collection protocol in the current study, they were unable to. The combination of these two things likely account for the differences in the measures between studies. The maximum heart rate values reported by Potteiger et al. (1992) fell between a range of 133-147 bpm while the current study measured HR between 135-173 bpm. The heart rate values measured during baseball pitching indicate that pitching primarily takes place in an aerobic/moderate intensity zone (Zone 2) with some pitchers working into an anaerobic endurance/high intensity zone (Zone 3). This may have applications when conditioning pitchers off the field when attempting to mimic the metabolic demands of pitching itself.

When examining the trials across innings, rather than across intervals, it was observed that pitching VO_2 and pitching $\%VO_2$ max stay comparatively consistent throughout the trial, with a slight increase between inning one and inning two and then a decrease between inning two and three. A reason for this decrease from inning two to inning three is in part due to a smaller amount of data analyzed for the third inning. Each pitcher was limited to three innings or 50 pitches, whichever event occurred first, resulting in some of the participants only facing one to two hitters in the third inning, while some did complete an entire third inning. If all participants would have finished out the third inning, there is a chance a different trend in the mean values for the third inning would have been reported. The physiological variables of HR and RER did not follow the same trend as the oxygen consumption variables as they decreased across all three innings, with the lowest values being reported in the third inning for both. This trend of decreasing values aligns with the previously reported in-game HR response Cornell et al. (2017) and contradicts the trends reported by Potteiger et al. (1992) where HR was lowest in the first inning and rose all the way to the fifth inning. This downward trend may be in part due to decreased psychological drive from progress through the trial with success and becoming accustomed to throwing with the respiratory mask on, but future studies should attempt to evaluate this.

The only relationship found between a physiological variable and a performance variable was an inverse relationship between the pitching $\%VO_2$ max and strike percentage ($r = -.864$, $p =$

.027). This provides evidence that pitchers who perform at a lower percentage of their VO_2 max tend to throw more strikes while facing hitters. This has interesting implications for players, coaches, and strength & conditioning professionals. While aerobic capacity does not seem to be a rate-limiting factor for performance, it does appear that being able to perform at a lower percent of VO_2 max does have a relationship with performance. A previous study reported that VO_2 max had low-to-moderate relationships with several performance variables (Gillett et al., 2016) including walks per nine innings ($r = -0.416$, $p < 0.05$), wins ($r = 0.548$, $p < 0.05$), strikeouts per nine innings ($r = 0.614$, $p < 0.01$), and earned run average ($r = -0.678$, $p < 0.01$). Considering the findings from the current study and previous research would provide support for implementing conditioning that increases aerobic capacity. If a pitcher increases their VO_2 max, they would in turn decrease the percentage of their VO_2 max they were working at while pitching.

Practical Application

The findings of the current study support the development and maintenance of maximal aerobic capacity (VO_2 max) for baseball pitchers at highly competitive levels. Pitchers who can perform at a lower percentage of their VO_2 max tend to have a higher strike percentage. For conditioning early in the off-season, this can be achieved through aerobic conditioning ranging from moderate-to-high intensities. Pitchers closer to their competitive season may want to perform high-intensity interval training (HIIT) involving plyometric type movements to increase aerobic capacity. The use of HIIT training has been previously shown to increase aerobic capacity (Buechheit & Laursen, 2013) and may increase VO_2 max without causing detriment to baseball specific power output (Rhea et al., 2008). For strength and conditioning professionals attempting to mimic the physiological demands of pitching, they should aim to prescribe exercises that require pitchers to maintain a HR between 70-80% of their HR maximum (aerobic/moderate intensity). It may be best done for extended periods of time with deliberate rest intervals between the working intervals so that the substrate utilization closely resembles that of pitching as well. It is much more practical to use HR as the physiological measure of intensity rather than oxygen consumption by pitchers, coaches, and strength and conditioning professionals in training and game settings, and due to the relationship between HR and oxygen consumption, this is still possible. However, for professionals in the industry with access to equipment necessary to perform GXT this study supports conducting VO_2 max testing and using it is an index of preparedness and performance for an upcoming season and performance. Perhaps a useful way to utilize the data from the GXT would be to determine where oxygen consumption is near 50% of their VO_2 max during the GXT and identify the corresponding HR for that athlete. Once they have identified the corresponding HR, they can use affordable and commonly available HR monitors to guide aerobic conditioning protocols. Then, following a conditioning program, perform a retest GXT and see if the HR at the corresponding $\%VO_2$ max has improved.

Limitations

A limitation of this study is the small sample size (n = 6) but the findings of this study may contribute to a priori sample analysis for future studies. This sample was a convenience sample and only included pitchers currently competing at two levels (Junior College and Professional baseball) which may limit is generalizability. Another limitation was the collection process and the addition of a respiratory mask to pitchers while pitching. While the apparatus and protective screen minimized interference with mechanics and movement of the delivery, this uncommon stimulus most likely affected the intent and performance of pitchers to some degree. Four of the six participants reported being able to disregard the presence of a mask and protective screen, while two of the six participants cited it as being very difficult to get familiar with. Five of the six participants reported lower than usual velocities due to a concern for harming the equipment, despite being explicitly told they would not cause any damage to the equipment. While the pitchers did face live hitters and threw in a competitive setting against players currently competing at the same level as them, this was still not an in-game setting. Even though the scenario was competitive, it may not have caused the same physiological responses as an in-season competition which is another limitation to this study design. However, collecting respiratory gases during a live setting would be impossible due to the restraints of current measuring devices and safety concerns for pitchers.

Conclusion

Coaches and strength and conditioning professionals at highly competitive levels should strive to design and implement conditioning strategies for pitchers that promote injury prevention and improve performance. Implementing strategies that are evidence-based promotes the continued innovation and effectiveness of sport science and training protocols across all sports. This descriptive study contributes to further understanding the physiological demands of pitching to hitters and provided a possible solution to collect respiratory gases during pitching by describing the parameters over time during live pitching. The ability of the current study to measure physiological parameters in conjunction with pitch metric data during living pitching to describe changes across intervals, as well as across innings, has helped further the physiological demands of pitching and a highly skilled level. The descriptions and findings of the current study warrant further research into the relationship between optimal conditioning protocols for highly skilled pitchers and their relationship to performance.

APPENDIX

Figure 9. *Correlation plot for Pitching Percent VO_2 Max and Strike Percent.*

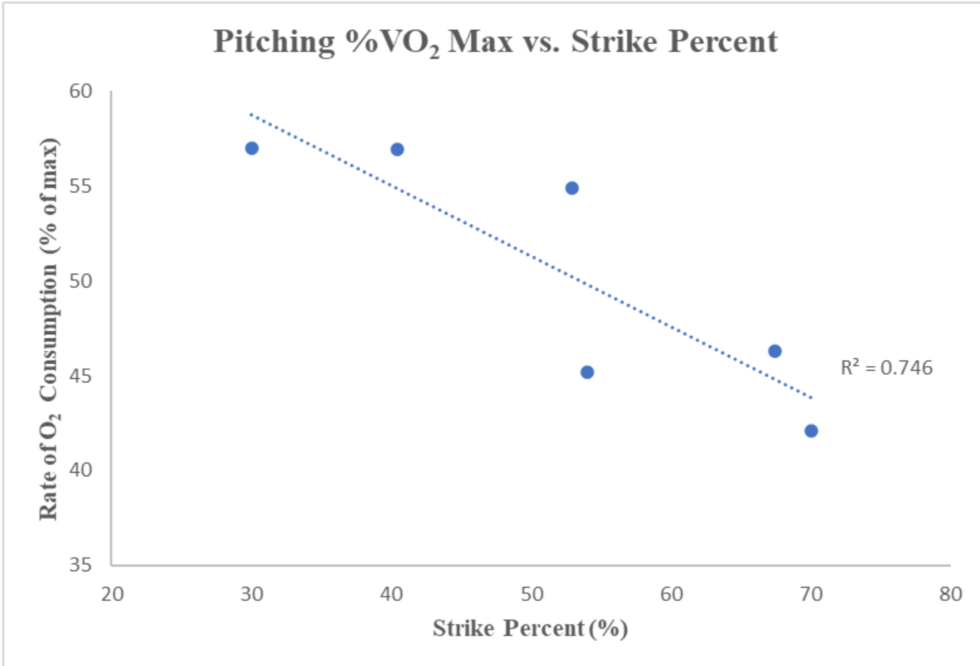


Figure 10. *Correlation plot for Max Fastball Velocity and Average Fastball Velocity.*

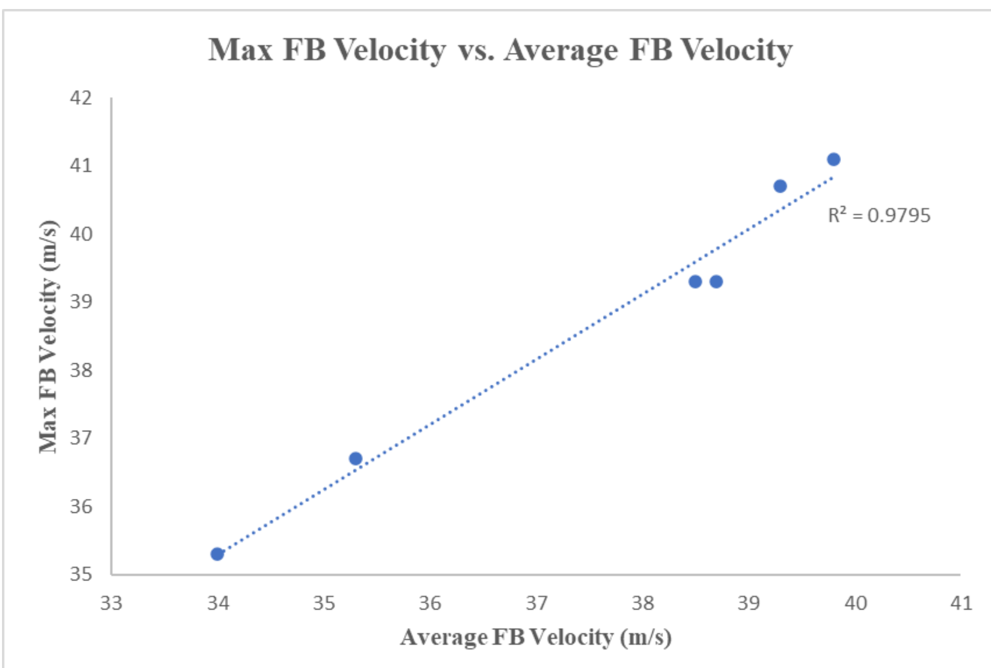


Figure 11. *Correlation plot for Pitching VO_2 and Pitching Percent VO_2 Max.*

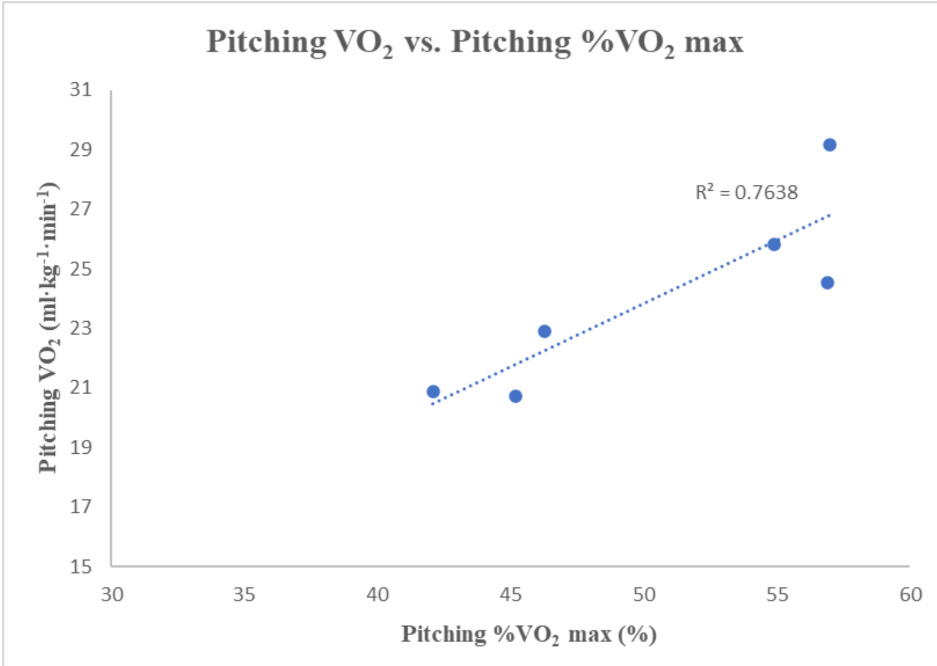
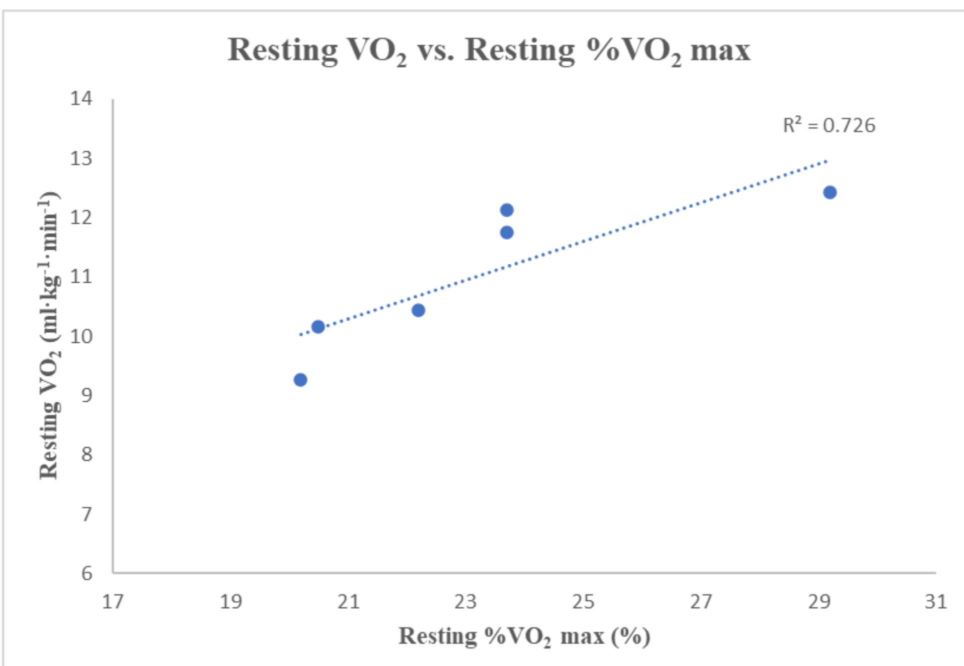


Figure 12. *Correlation plot for Resting VO_2 and Resting Percent VO_2 Max.*



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CURRICULUM VITAE

Jesse Clingman - j.clingman8@gmail.com

Educational Background

M.S. Kinesiology – University of Nevada – Las Vegas *May 2023

B.S. Exercise Science - Dixie State University May 2020

◆ Cumulative GPA: 3.81 ◆ Dixie State University GPA: 3.99 ◆ Major GPA: 3.99

A.S. General Studies - Salt Lake Community College May 2015

SCHOLARLY & ACADEMIC EXPERIENCE

- Graduate Research Assistant – Assist in all aspects of research with Dr. John Mercer at University of Nevada- Las Vegas. Responsibilities include:
    - Collecting, coding, and/or analyzing data
    - Conducting literature reviews or library research
    - Preparing materials for submission to funding agencies and foundations
    - Writing reports
    - Preparing materials for IRB review
- Graduate Teaching Assistant – Lecture and guide learning for undergraduate lab sections at University of Nevada, Las Vegas. Responsibilities include:
    - Prepare and present weekly lecture materials
    - Guide student learning through lab activities and data collection.
    - Grade and submit student grades.
- Biomechanics and Sports Science Lab Coordinator – Assist on install and calibration of lab equipment as well as planning of weekly meetings and coordinating research club activity to promote learning through research.
- Previous and current research:
    - **In progress:** Mercer, J., **Clingman, J.** Oxygen Consumption on Highly Skilled Baseball Pitchers. University of Nevada, Las Vegas. Las Vegas, NV.
    - **In progress:** Mercer, J., **Clingman, J.,** Ollano, V. Investigation of Heated Trousers on Cycling. University of Nevada, Las Vegas. Las Vegas, NV.
    - **In progress: Clingman, J**., Clingman, T., Clarkson, T., Gottfredson, N., and Ficklin T.K. (postponed) Descriptive Study of Free Moment in Skilled Overhand Throwers. Dixie State University Regional Research Symposium. Saint George, UT.
        - **Data collection completed on 02/25/2020. Data analysis in progress.**
    - **Clingman, J**., Lindsley, K., Richardson, S., Del Toro, E., Bowles, B., and Ficklin T.K**.** (2019) Hip and shoulder separation and its relationship to pitched baseball velocity. Dixie State University Regional Research Symposium. Saint George, UT.

- Invited presentation (2019) -- Measurement and Evaluation in Physical Exercise and Sports – Presented on the importance of understanding common statistical research values and data collection in an applied setting.
- Invited presentation (2019) – Activity Programming for Special Populations – Presented on the Bruininks-Oseretsky Test of Motor Proficiency (BOT2) and helped guide the class through testing in each of the subcategories.
- (Ongoing) Programming and Report Production – Self-taught programmer in RStudio and MATLAB. Generate reports to help guide recruiting reports, generate reports on player performance, and execute analytical geometry.
- Member of Dixie State University Pre-Health Professionals Club – attend bi-weekly meetings, help develop volunteer opportunities for club members, and helped promote club service projects.
- Invited presentation – All Classes, Exercise Science Program – presented in classes all throughout the program at the request of the Academic advisor in the Health and Human Performance department to promote a proactive approach to applying for graduate school, obtaining volunteer and shadowing hours, registration plans, and developing a career path early on in undergraduate degree.

SERVICE AND APPLICABLE SKILLS

- Volunteer at the St. George Marathon – Mile 6 – First Aid Station.
- Volunteer at the Special Olympics Basketball Tournament at Dixie State University.
- Conducted over 750 three-dimensional motion capture assessments for collegiate and professional baseball players.
- Intercollegiate athletics - baseball; named team captain in final year.
- Named Dixie State University Baseball Director of Analytics
- Completed first ever data collection conducted in Dixie State University Human Performance Center Building

AWARDS

- 2020 American Kinesiology Association Regional Student of the Year
- 2020 Dixie State University College of Health and Human Performance Student of the Year
- Dixie 11 Award Finalist