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Graduate Studies

A COMPARISON OF NEUROMUSCULAR FATIGUE LEVELS IN COLLEGIATE
BASEBALL CATCHERS AND POSITION PLAYERS
OVER A COMPETITIVE SEASON

A Manuscript Style Thesis Submitted in Partial Fulfilment of the Requirements for the
Degree of Master of Science

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Applied Sports Science

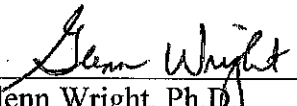
May, 2017

A COMPARISON OF NEUROMUSCULAR FATIGUE LEVELS IN COLLEGIATE
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By Kathryn A. Cardwell

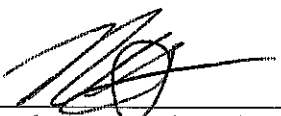
We recommend acceptance of this thesis in partial fulfillment of the candidate's requirements for the degree of Master of Science in Human Performance (Applied Sports Science Emphasis).

The candidate has completed the oral defense of the thesis.



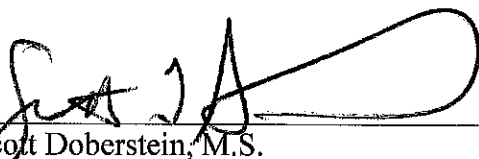
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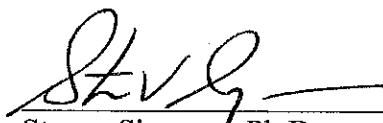
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ABSTRACT

Cardwell, K.A. A comparison of neuromuscular fatigue levels in collegiate baseball catchers and position players over a competitive season. MS in Human Performance, May 2017, 63pp. (G. Wright)

PURPOSE: The purpose of this study was to investigate the development of neuromuscular fatigue of collegiate baseball players throughout the course of a competitive season. A secondary purpose was to determine if a difference of accumulated fatigue exists between baseball catchers, infielders and outfielders. **METHODS:** Thirty-Three Division II and III baseball players performed non-weighted countermovement and squat jumps on a force plate over 3 different testing sessions throughout a competitive season. Flight time: Contraction time (FT:CT) ratio and Eccentric Utilization Ratio (EUR) values were calculated using the variables derived from the force plate. Subjects also completed a Training Distress Scale survey at each of the testing sessions to assess subjective stress levels. **RESULTS:** A significant increase in FT:CT in baseball players over the course of the season was detected between pre- and postseason ($p=.001$) and mid- and postseason ($p=.005$). No significant difference was detected using EUR over the course of the season ($p=.853-1.00$) or between positions ($p=1.00$). There was a significant increase in TDS scores between pre- and midseason ($p=.054$). **CONCLUSION:** Results indicated that there was no evidence of neuromuscular fatigue development in collegiate baseball players throughout the course of the season.

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INTRODUCTION

Collegiate baseball teams are subject to compacted seasons, often tasked with playing 40 games within an eight-week period, traveling multiple times per week and playing frequent doubleheaders. Further, players must balance classes, extracurricular work, and the stresses that families and relationships bring. With this demanding schedule and additional sources of stress, the development of fatigue can create a dramatic decline in performance both offensively and defensively over time.

Additionally, because of the different requirements of each position, the amount of accumulated fatigue has the potential to vary widely between positions within a baseball team. While infielders and outfielders are able to relax between pitches or batters, catchers are required to be in constant motion throughout the game, rising between a crouch and a standing position between every pitch, occasionally rising explosively when trying to throw a runner out at second or third base. As this position involves a great deal of mental concentration, physical resilience, and a specific skill set, often times, teams will rely heavily upon one or two people to fulfill this role for a full season. However, it has not yet been studied if catchers fatigue at a similar or greater rate than their position player counterparts.

Although research on fatigue in baseball players has been limited, over the past decade, there has been a growing number of studies investigating changes in stretch-shortening cycle performance as an indicator of neuromuscular fatigue across a wide range of sports. By calculating a ratio of flight time by contraction time (FT:CT) during a

countermovement jump (CMJ), Cormack, Newton, & McGuigan (2008a) demonstrated that fatigue was represented by a decline in FT:CT following an Australian Rules Football (ARF) match, as well as further declines in FT:CT as the ARF season progressed (Cormack, Newton, McGuigan, & Cormie, 2008b). The FT:CT ratio has also been used to monitor the accumulation of neuromuscular fatigue in amateur baseball players during an eight-day national tournament, displaying marked decreases in FT:CT ratios beginning on the third day of the tournament (Nimphius, 2011).

Another method of analyzing stretch-shortening cycle performance, the eccentric utilization ratio (EUR), has been widely used as a measure of detecting changes in training status of athletes (McGuigan et al, 2006; Doyle, 2007; Hawkins, Doyle, & McGuigan, 2009). The EUR is a ratio between the jump height or peak power output during a CMJ with the corresponding variables from a squat jump (SJ) ($EUR = CMJ/SJ$). Previous research on EUR comparing five different sports (rugby union, ARF, softball, field hockey, and soccer) determined that athletes in those sports with a greater reliance on the stretch-shortening cycle exhibited higher EUR values (McGuigan et al., 2006). It has also been demonstrated that EUR values increase as strength training progresses, likely due to improved CMJ performance (Doyle, 2005; McGuigan et al., 2006). Although it has not been used in this manner previously, the comparison the EUR makes between CMJ and SJ performance has the potential to be useful as an evaluation for tracking neuromuscular fatigue, as decreases in jump performance would likely reduce the ratio between the two.

In addition to reductions in stretch-shortening cycle performance, fatigue can also impair the mental state of an athlete, further leading to declines in performance. While

fatigue can be measured through performance measures such as FT:CT and EUR, occasionally the use of subjective measures, such as questionnaires, are an alternative approach of monitoring training loads when physiological tests are impractical. In addition, they have also been shown to be a better and more reliable indicator of fatigue compared to physiological testing (Saw, Main, & Gastin, 2015). The Training Distress Scale (TDS) was designed to assess individual responses related to general fatigue, muscle soreness, emotional status, sleep disturbances, concentration difficulties and appetite changes that have occurred during the previous 48 hours (Grove et al., 2014). While research demonstrating the validity of the TDS as a measure of short-term training distress and performance readiness exists, the TDS has yet to be used as a comparison of fatigue levels among different positions on a sports team.

Keeping these considerations in mind the purpose of this study was to investigate the development of neuromuscular fatigue of collegiate baseball players throughout the course of a competitive season. A secondary purpose was to determine if a difference of accumulated fatigue exists between baseball catchers, infielders, and outfielders. It was hypothesized that baseball players would display signs of neuromuscular fatigue throughout the season and catchers would fatigue at a greater rate when compared to other members of the team, due to the continuous strain they are subjected to during a game.

METHODS

Experimental Approach to the Problem

The purpose of this study was to investigate the development of neuromuscular fatigue of collegiate baseball players throughout the course of a competitive season. Unloaded CMJ and SJ were used as the independent variables. The dependent variables were FT:CT and EUR based on jump height. Subjects completed unloaded CMJ and SJ on three separate occasions throughout the regular season. Subjects also completed a 19-question survey to assess additional sources of fatigue at each jump testing session. Comparisons were made between the FT:CT and EUR during these three testing sessions to assess the demands on reactive strength.

Subjects

Thirty-three men (height: 182 ± 6.83 cm; weight: 86.9 ± 8.71 kilograms) from four separate collegiate baseball teams were recruited to participate in this study. Two subjects were dropped from the study for not completing all testing, leaving the final analysis for 31 subjects. Three teams played at the NCAA Division III level, while one team played at the NCAA Division II level. For inclusion, subjects were required to be between the ages of 18-24, at least one year of prior collegiate baseball experience, and were expected to get the majority of starts throughout their season as predicted by their coach. Subjects consisted of 9 catchers, 11 infielders, and 11 outfielders. This study was approved by the Institutional Review Board at the University of Wisconsin-La Crosse

and additional permission was granted from the other universities that participated prior to the start of data collection. All subjects read and signed a written informed consent form before participation.

Procedures

Each athlete participated in three testing sessions throughout the course of the season: the week prior to the start of the competitive season, approximately halfway through the season, and within the final week of the competitive season. All testing was conducted at the home university of each team participating, eliminating travel organization and reducing the time commitment involved for the subjects. Prior to testing, subjects completed a standardized warm-up that consisted of jogging approximately 200 meters, 10 walking lunges, and 10 tuck jumps. Subjects were then asked to complete four single, maximal effort CMJs with a 30 second rest between jumps. Subjects were instructed to jump as high and as fast as possible using a self-selected counter movement depth. Hands were placed on hips to remove any additional benefit gained by upper body motion. Squat jumps were performed in a similar manner, with subjects completing four single, maximal effort jumps with a 30 second rest between jumps. Subjects flexed their knees to a self-selected squat depth, held it for approximately three seconds, then jumped as high as possible from that position. Again, hands were placed on hips to remove additional benefit gained by upper body involvement. Following each testing session, subjects also completed a TDS (Grove et al., 2014).

All jumps were performed on a portable force plate (Kistler Quattro Jump; Kistler Instrument Corp., Amherst, NY) sampling at a frequency of 500 Hz, which was calibrated immediately prior to each use and was placed on the same level surface during

each testing session. Squat jumps were considered valid when it was determined that the subject displayed an eccentric movement involving less than 7% of their body mass during the jump. The involvement of <7% of body mass was chosen as it provided the most valid data points with limited eccentric movement. The calculations of the potential eccentric movement were completed using custom-written MATLAB scripts (MathWorks, Natick, MA). Flight time, contraction time, jump height, and FT:CT for each jump were also calculated through additional custom-written MATLAB scripts. The best CMJ and SJ, determined by greatest jump height, of all trials within each testing session was then used for data analysis. Data for EUR was generated by using the jump height of the best CMJ divided by the jump height of the best SJ (McGuigan et al., 2006).

Statistical Analysis

Means and standard deviations (mean \pm SD) were calculated for each variable. Prior to comparison, a Levene's test for homogeneity of variance was completed to evaluate the variance equality between the groups. A two-way ANOVA with repeated measures (3 positions x 3 collection times) was used to determine significant interaction between variables. If significance was observed, a Bonferroni's post hoc test was used to identify where differences existed. An alpha level of $p < 0.05$ was set as the measure for significance. Cohen's d effect sizes were calculated for differences between preseason and other testing sessions. When Cohen's d was 0.0, 0.2, 0.6, 1.2, 2.0, and 4.0, effect sizes were interpreted as trivial, small, moderate, large, very large, and nearly perfect, respectively, based on the scale by Hopkins (2002). Pearson correlations were calculated between number of innings played, FT:CT, EUR, and TDS scores (Hopkins, 2002).

Statistical analyses were processed using SPSS (Version 24.0; IBM Corporation, New York, USA).

RESULTS

No statistically significant differences in the homogeneity of variance existed between positions or over time within Levene's test for FT:CT, EUR, and TDS, and thus, equal variances were assumed.

Flight Time: Contraction Time

There was an increase in FT:CT in baseball players over the course of the season ($p=.004$) with significant differences between pre- and postseason ($p=.001$, $d=.554$) and mid- and postseason ($p=.005$, $d=.481$); However, no difference was observed between pre- and midseason FT:CT ($p=1.00$, $d=.030$) (Figure 1). No significant differences in FT:CT were identified between positions over the course of the baseball season ($p=1.00$; $d=.033-.386$) (Figure 2). In addition, no interaction between time and position was identified for FT:CT ($p=.648$) (Figure 3).

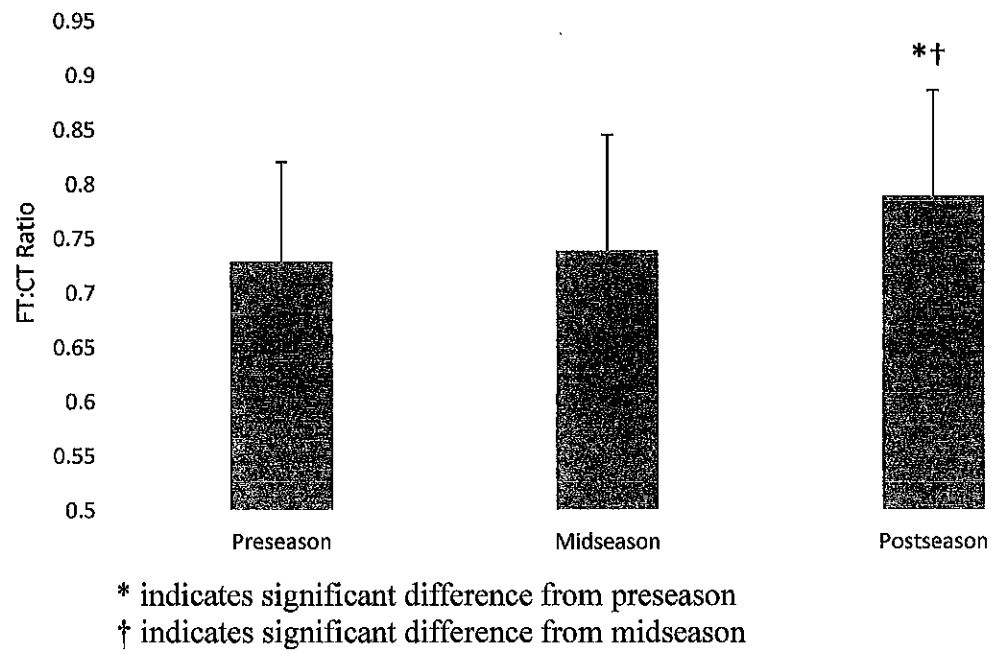


Figure 1. Flight time: Contraction time main effect by time

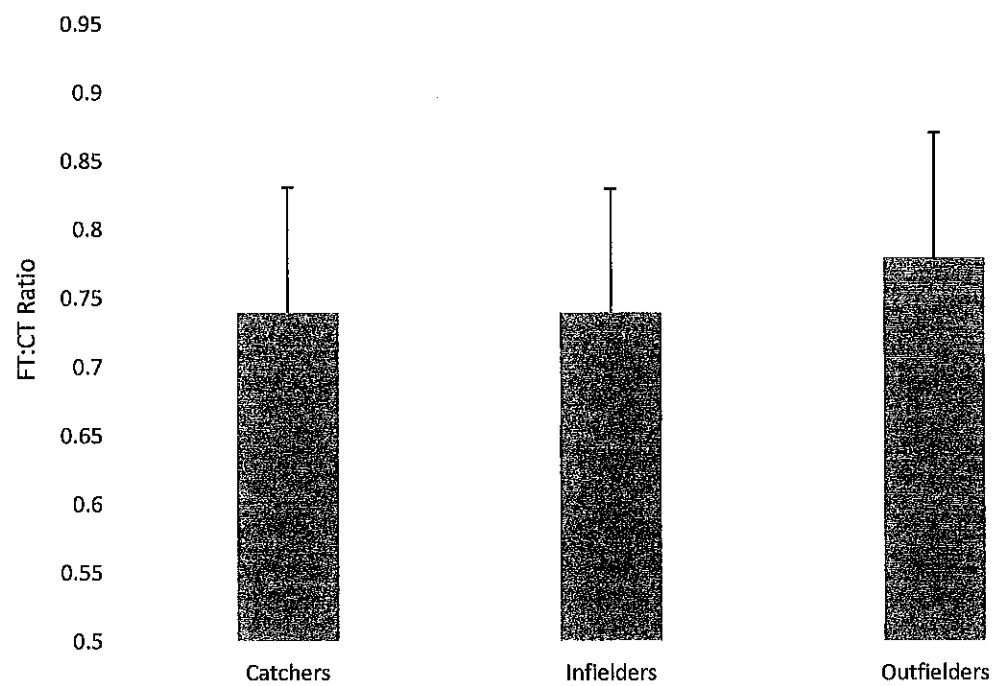


Figure 2. Flight time: Contraction time main effect by position

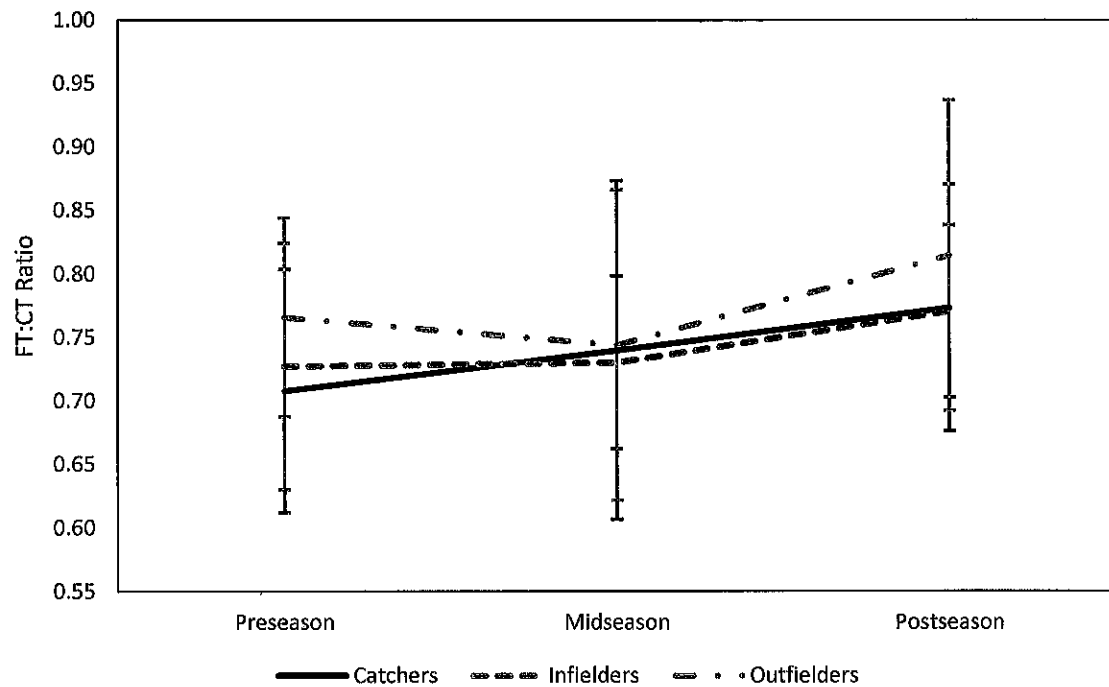


Figure 3. Flight time: Contraction time interaction (time x position)

Eccentric Utilization Ratio

Due to some subjects not meeting the established criteria for valid squat jumps, the data for EUR was limited to 6 catchers, 8 infielders and 6 outfielders ($n = 20$). In general, baseball players showed no significant differences in EUR across the season ($p=.853-1.00$, $d=.084-.376$) (Figure 4) or by position ($p=1.00$, $d=.034-.275$) (Figure 5). In addition, no significant time by position interaction ($p=.726$) (Figure 6).

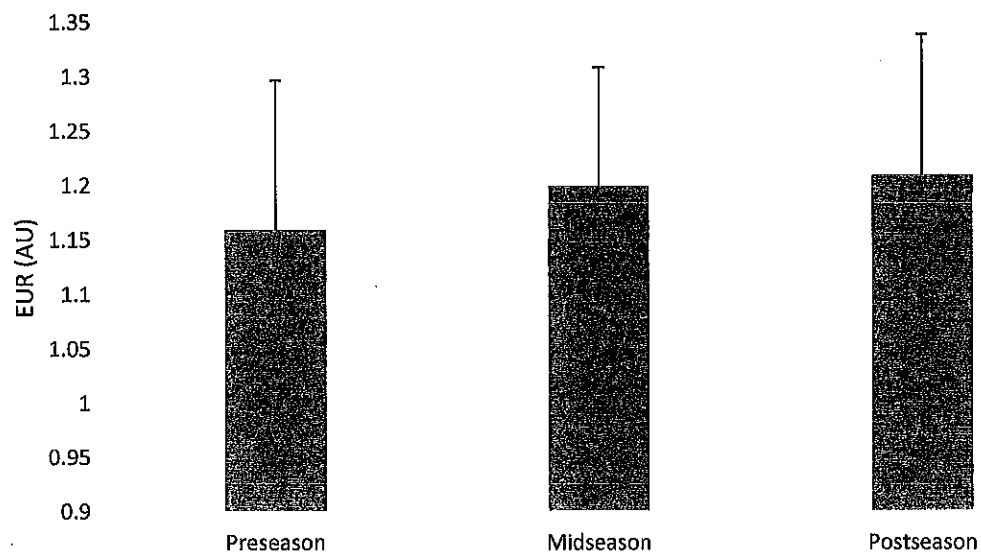


Figure 4. Eccentric utilization ratio main effect by time. AU=arbitrary units

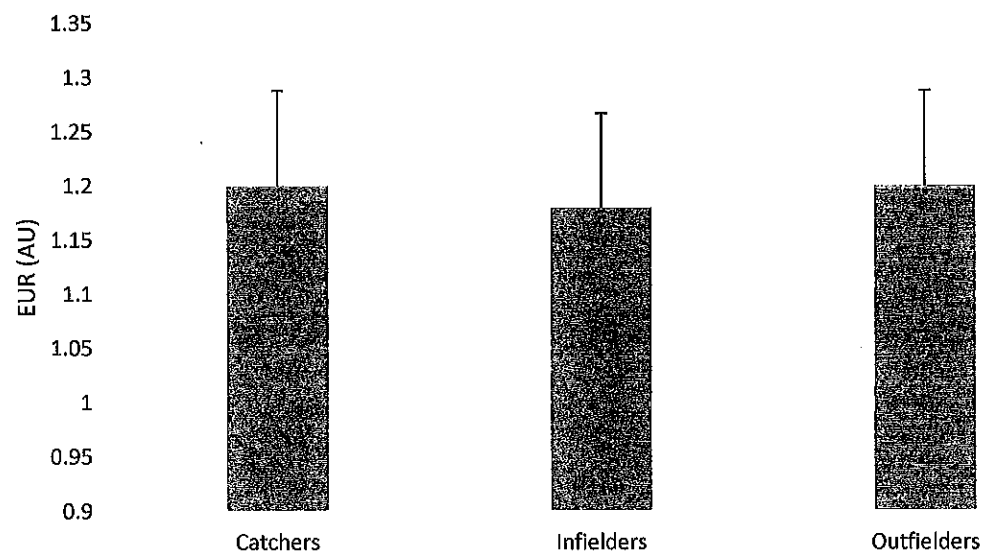


Figure 5. Eccentric utilization ratio main effect by position. AU=arbitrary units

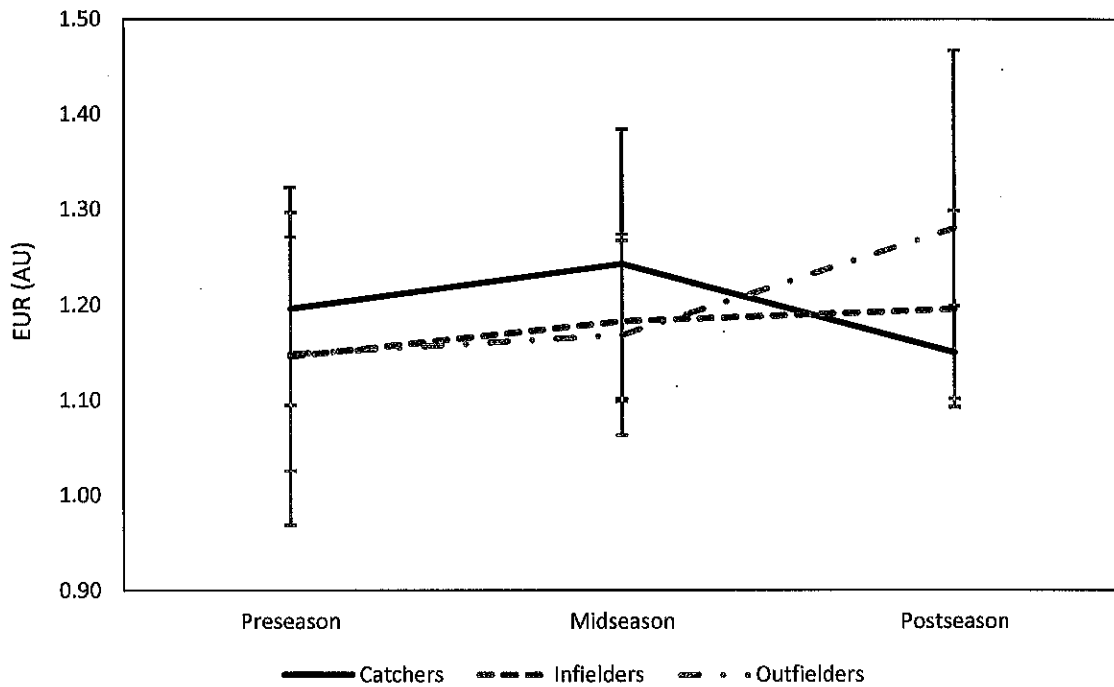


Figure 6. Eccentric utilization ratio interaction (time x position)

Training Distress Scale

Baseball players in this study showed a significant increase in TDS scores between pre- and midseason ($p=.054$, $d=.404$) with no significant change observed between mid- and postseason ($p=1.00$, $d=.034$). However, there was no difference in TDS identified between pre- and postseason ($p=.088$, $d=.376$) (Figure 7). No significant main effect by position was detected ($p=.839-1.00$, $d=.147-.481$) (Figure 8). No significant time by position interaction was detected ($p=.726$) (Figure 9).

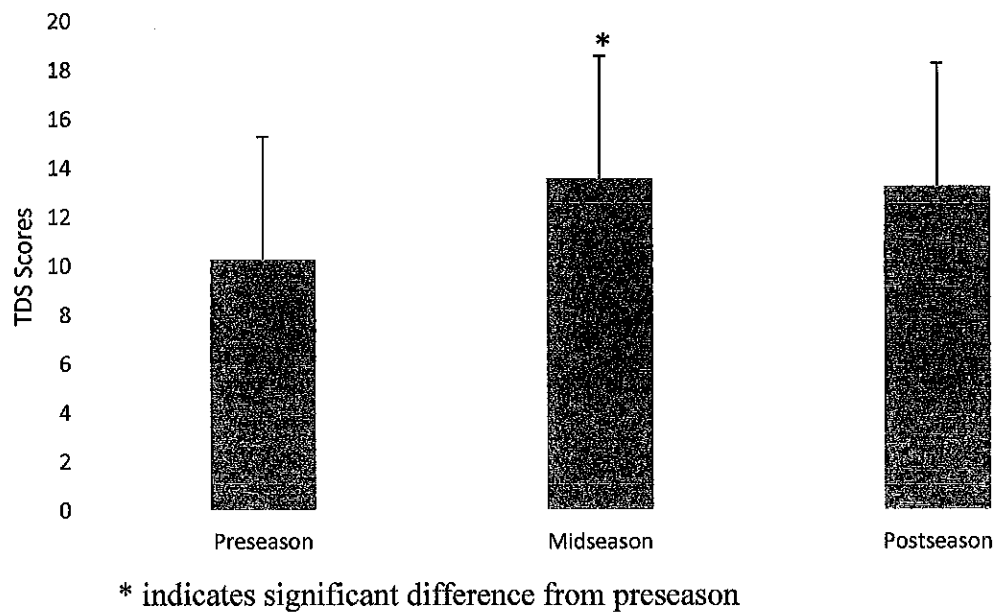


Figure 7. Training distress scale scores by time

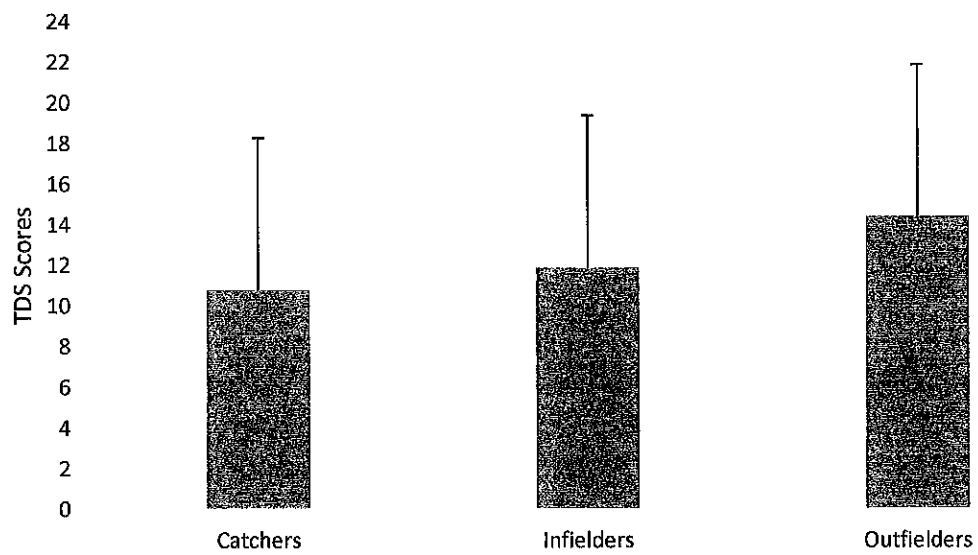


Figure 8. Training distress scale scores by position

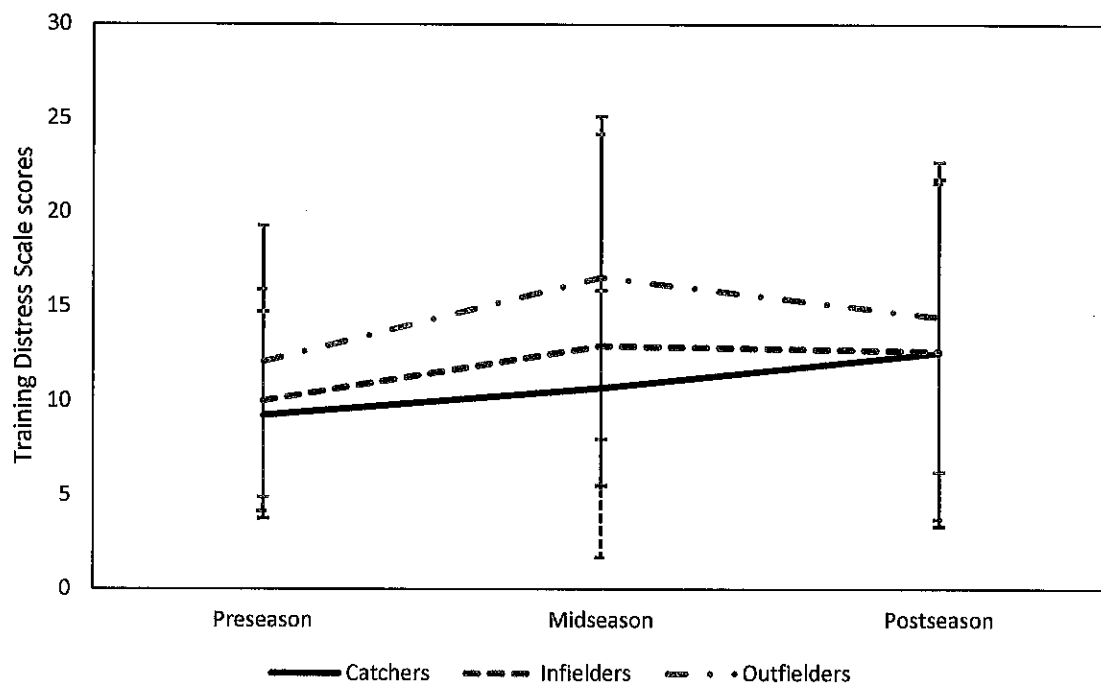


Figure 9. Training distress scale interaction (time x position)

Correlations

A significant moderate relationship was detected between FT:CT and EUR ($r = .36, p = .002$), but no other significant correlations were identified between FT:CT, EUR, TDS, and innings played ($r = .02-.13, p = .47-.84$).

DISCUSSION

The primary purpose of this investigation was to examine the development of neuromuscular fatigue of collegiate baseball players throughout the course of a competitive season. A secondary purpose of the study was to determine if a difference of accumulated fatigue existed between baseball catchers, infielders, and outfielders. No evidence of accumulated fatigue was detected over the course of the season in baseball players in general or between positions utilizing criteria based on changes in FT:CT, EUR or TDS.

While a significant difference was detected in FT:CT ratios over time, this was represented by an increase in FT:CT rather than a decrease, the expected response due to fatigue. A possible explanation of this is that players may have demonstrated a learning effect during the 3 testing periods. Since a familiarization phase was not used due to the time constraints of the teams, it is likely that the subjects learned how to utilize their stretch-shortening cycle quickly and undergo a more rapid contraction time with each testing session as the season progressed. As a result, even if jump height did not change, an improvement (decrease) in contraction time would lead to an increased FT:CT ratio. This conclusion is supported by a significant decrease in contraction time throughout the season by all subjects ($p=.005$, data not shown), while flight time exhibited no significant change ($p=.665$, data not shown). To counter this effect in future studies, it is

recommended that subjects undergo a familiarization of the task to be tested prior to the start of data collection.

An alternative explanation for the lack of significance in FT:CT ratios could be the result of the level of training within subjects. Previous research has demonstrated that decreases in FT:CT are associated with fatigue in elite athletes training for high physical demanding sports (Cormack et al., 2008a; Cormack et al., 2008b; Nimphius, 2011); however, it could be speculated that the volume and intensity during training and competition, level of experience, and conditioning of the subjects in earlier studies far exceeds that of training and competition for Division II and III collegiate baseball, therefore allowing fatigue to be detected more easily. Cormack et al. (2008a; 2008b) focused on neuromuscular fatigue development in professional ARF players following a single match and throughout a 22-match season. While baseball does rely upon the stretch-shortening cycle for movements like batting, running and jumping, the intermittent nature of the sport, with frequent, moderate to long duration pauses in action, may prevent large accumulations of fatigue. In contrast, the degree of external load and training intensity that ARF requires from the stretch-shortening cycle is more uninterrupted and offers less recovery time during play, with four quarters each lasting twenty minutes, involving frequent sprints and vertical jumps. With the greater demand for stretch-shortening cycle action and more continuous play, it seems logical that studies utilizing ARF players would demonstrate a clear decline in FT:CT values following a single match and continue to decline throughout the season, whereas less highly trained collegiate baseball players might not display the same effect.

Finally, subjects in previous studies were tested for changes in FT:CT values on a greater frequency than the current study. In addition to the greater intensity that ARF players perform at, subjects in both Cormack studies (2008a; 2008b) were tested on a weekly basis. While Nimphius (2011) was able to detect neuromuscular fatigue in baseball players tested daily, the study was conducted during a tournament where subjects played eight games in eight days, leading to a greater accumulation of fatigue that may have been detected more easily. Further research should conduct testing weekly, if not daily, to appropriately monitor short-term changes in neuromuscular fatigue levels in baseball players.

Though there have been several studies that have used EUR to assess lower body stretch-shortening cycle performance of athletes over various training periods (McGuigan et al., 2006; Doyle, 2007; Hawkins, Doyle, & McGuigan, 2009; Suchomel, Sole, & Stone, 2016), the current study is the first to employ EUR as a method of monitoring neuromuscular fatigue levels over a competitive season. It was hypothesized that there would be a decrease in EUR values over the course of the season for all positions, with the greatest expected decline found in catchers. Yet, no significant decreases in EUR scores for any position were detected. This result may be due to the possibility that the EUR lacks the sensitivity to detect changes in stretch-shortening cycle performance. One of the limitations of using a ratio such as EUR is that subjects may increase the depth of the countermovement to increase the impulse when fatigued, therefore increasing the contraction time leading into the jump to maintain vertical height. While there may be small changes in jump heights from CMJ and SJ, unless there are significant increases in one variable over the other, the ratio between the two will be minimal, leading to a lack

of significance. This was demonstrated in the 8-week training study by Hawkins, Doyle, & McGuigan (2009), where increases in CMJ height corresponded with increases in SJ height, resulting in non-significant changes in EUR over the training period. In comparison, the FT:CT ratio takes this possibility into consideration, as changes in impulse would be evident in contraction time. Therefore, EUR, when calculated using jump height of both CMJ and SJ, may not be an appropriate measure for monitoring neuromuscular fatigue over a competitive season.

Results of the current study displayed a significant increase in TDS scores, indicating an increase in stress, between pre- and midseason. Midseason testing was conducted near the time when colleges were administering midterm exams, which may explain the increase in stress felt by the subjects (Kennedy, Tamminen, & Holt, 2013). In addition, there was no significant change in TDS scores detected between mid- and postseason, which may also be related to the fact that postseason testing for two teams was conducted during finals week and the other two teams, during the last week of classes. However, it is necessary to note that there was no significant difference between pre- and postseason TDS scores. Future investigations should administer the TDS on weekly or bi-weekly basis to fully incorporate a more sensitive measure of changes in stress, rather than just those felt at times of academic stress. Furthermore, prior to this investigation, the TDS (Grove et al., 2014) has only been validated as a measure of perceived stress throughout training sessions by the creators of the assessment. In their initial study, they presented the findings that TDS scores decline as the amount of physical and mental strain on an athlete accumulates over time. However, the testing protocols that were utilized by Grove et al. (2014) were of a greater intensity than would

be typically found in a baseball game or practice, with two phases of the study employing high intensity treadmill and cycle ergometer workouts multiple times a day. Therefore, it may be that the intermittent nature of intense activity seen in baseball may not be as stressful as the activities in the original study using TDS (Grove et al. 2014).

The secondary purpose of this study was to determine if there was a difference in the level of accumulated fatigue between catchers, infielders and outfielders. It was hypothesized that catchers would demonstrate a decline in stretch-shortening performance at a greater rate than their position player counterparts due to the constant strain that catchers place upon the muscles of their lower body by squatting to get into position for every pitch. The results indicated there was no significant difference in the development of neuromuscular fatigue between positions. Again, this result can possibly be explained by the learning effect that occurred, as it is likely that subjects from each playing position improved their ability to use their stretch-shortening cycle more effectively with each testing session. The possibility also exists that baseball catchers are accustomed to the stresses they place on their lower body and develop fatigue at the same rate as position players; however, this theory remains to be proven and future studies should continue to investigate this likelihood.

In conclusion, the current study indicates that there was no significant difference in the accumulation of neuromuscular fatigue among positions on a collegiate baseball team. While there was evidence of changes in FT:CT, these results were likely due to a learning effect by the subjects. Increases in TDS may also be explained by the increase in academic stressors during midterm and final exams. As such, there is little evidence to support the hypothesis that collegiate baseball players exhibit significant amounts of

neuromuscular fatigue over a competitive season. Further investigations are needed to track training loads during a baseball season to determine if high intensity work is done to produce fatigue at a significant level.

Practical Applications

Future investigations should take care to allow subjects time for a familiarization period with the testing methods being utilized to eliminate the presence of a learning effect. Further, investigators ought to be aware of the additional academic stresses that collegiate athletes encounter during competitive seasons and recognize the potential impact that they may have on performance and performance testing. Additionally, if FT:CT, EUR, or TDS are used with the intent of monitoring fatigue in collegiate athletes, it is recommended that testing is performed on a weekly or bi-weekly basis so that any detectable changes in stretch-shortening performance can be identified and monitored closely to prevent athletic performance decline.

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APPENDIX A
INFORMED CONSENT FORM

Informed Consent

Protocol Title: A Comparison of Neuromuscular Fatigue Levels in Division III Collegiate Baseball Catchers and Position Players Over a Competitive Season

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- **Purpose and Procedure**
 - The purpose of this study is to determine if catchers' leg muscles fatigue at a faster rate than other position players during a season.
 - My participation will involve completing a few warm-up exercises, jumping on a force plate several times, and filling out a 19-question survey asking about the current level of my fatigue.
 - Testing will take place three times throughout my season: Once just before the season starts, once halfway through, and once near the end of the season.
 - It is estimated that each testing session will take about 15 minutes total. I should not feel worn out after completing my testing session.
- **Potential Risks**
 - There is a small risk that I could injure myself while completing the jumping protocol. Every attempt to minimize this risk will be taken by the research team.
 - The risk of serious or life-threatening complications, for healthy individuals, like myself, is near zero.
- **Rights & Confidentiality**
 - My participation is voluntary. I can refuse to answer any question without consequence at any time.
 - I can also withdraw from the study at any time for any reason without penalty.
 - The results of this study may be published in scientific literature or presented at professional meetings using grouped data only.
 - All information will be kept confidential through the use of number codes. My data will not be linked with personally identifiable information.
- **Possible Benefits**
 - I and other athletes may benefit by understanding how fatigue impacts baseball catchers and position players over the course of a season.

Questions regarding study procedures may be directed to the principal investigator or the study advisor, Dr. Glenn Wright, Department of Exercise and Sport Science, UW – La Crosse (608) 785-8689. Questions regarding the protection of human subjects may be addressed to the UW – La Crosse Institutional Review Board for the Protection of Human Subjects, (608-785-8124 or irb@uwlax.edu).

Participant _____ Date _____

Researcher _____ Date _____

APPENDIX B

REVIEW OF LITERATURE

**A Comparison of Neuromuscular Fatigue Levels in Collegiate Baseball Catchers
and Position Players Over a Competitive Season – A Review of Related Research
Literature**

Introduction

Many studies have been conducted to analyze the mechanics, the physiological stresses, and the action of pitching a baseball from the mound to home plate. However, there has been little investigation into the accumulation of fatigue in baseball, and even less in catchers and position players on a baseball team. With seasons lasting several months and few rest days built into the schedule, the development of fatigue may create a dramatic decline in performance both offensively and defensively over time.

Additionally, the amount of accumulated fatigue can vary widely between positions within a baseball team. While infielders and outfielders are able to relax between pitches or batters, catchers are required to be in constant motion throughout the game, rising from a crouch to a standing position between every pitch, often rising explosively when trying to throw a runner out at second or third. As this position involves so much mental concentration, physical resilience, and a specific skill set, often times, teams will rely heavily upon one or two people to fulfill the role for a full season. Furthermore, with unyielding schedules and few days off between games, catchers run the risk of overtaxing their muscles and lowering their performance ability. However, it has not yet been studied if catchers fatigue at a similar or greater rate than their position player counterparts. It could be speculated that, as catchers are familiar and trained in the

demands of their position, their muscles are accustomed to the stresses of this position, lessening the amount of fatigue that accumulates throughout a typical game or season.

The starting catcher of the San Francisco Giants, Buster Posey, serves as an example of the workload often shouldered by professional catchers. From 2011 to 2015, Posey played an average of 127 games per year, serving as catcher in 77% of those contests and filling in at first base or designated hitter in the remaining 23% (Sports Reference LLC, n.d.-a). As a point of reference, the Major League Baseball regular season is 162 games long. Besides assuming the crouch position for each pitch of the entire game, he was also challenged by opposing team players attempting to steal bases 360 times throughout these five years, requiring him to spring out of his crouch rapidly and throw the baseball on target to second or third base as quickly as possible. Incredibly, during that time, he was successful throwing out opposing players 31% of the time (Sports Reference LLC, n.d.-a). Similarly, Salvador Perez, primary catcher for the Kansas City Royals, started as catcher in 535 out of 544 games during the 2011-2015 seasons (Sports Reference LLC, n.d.-b). During that time, he successfully threw out 32% of attempted stolen bases against him (Sports Reference LLC, n.d.-b). Additionally, over a five-year average, Posey and Perez have batting averages of .309 and .288, respectively (Sports Reference LLC, n.d.-a; Sports Reference LLC, n.d.-b), indicating a large contribution to offensive play for their teams as well. Both of these men are exceptional athletes and demonstrate their skills on a daily basis at the highest level of their sport. However, one could speculate that by providing Posey or Perez with an additional day of rest occasionally, their lower body reactive ability in moving from crouch to throwing position may improve and potentially increase the rate of throwing out attempted stolen

bases or even bolster their offensive performance. As both the Kansas City Royals and the San Francisco Giants appeared in the World Series multiple times during the years these statistics were collected, decreasing the amount of fatigue that impacts two of their most valuable players could make these teams even more challenging to defeat.

While their seasons are not nearly as long as professional baseball teams, collegiate baseball players run the risk of developing performance-impacting fatigue throughout the course of a season as well. NCAA Division III teams on average play approximately 40 games within an eight-week period, often traveling multiple times per week. In addition, players are tasked with balancing classes, extracurricular work, and the stresses that families or relationships bring. As Major League Baseball begins to recognize the impact that fatigue has on player performance (Berra, 2015; Costa, 2015), there is hope that more research and work will be done on this population of athletes. Until that time, sport performance fatigue research can be conducted on collegiate teams, as they experience similar demands over a shorter period of time.

Over the past decade, there has been a growing amount of literature investigating fatigue through a variety of different methods across a wide range of sports. This review of literature will attempt to provide an extensive analysis of current research related to neuromuscular fatigue, how fatigue levels may be compared among positions on a baseball team, and where research should focus next in monitoring fatigue among baseball players.

What is Fatigue?

Muscle fatigue has been defined as any exercise-induced reduction in the ability to exert muscle force or power, regardless of whether or not the task can be sustained

(Bigland-Ritchie & Woods, 1984). As simple and straightforward as this definition is, the process of determining underlying causes of fatigue is not as direct. Muscular contraction is initiated when a stimulus is sent from the nervous system down an alpha-motor neuron by way of an action potential, a brief depolarization of membrane potential causing an electrical charge to travel along the axon. As the action potential reaches the end of the axon, the release of the neurotransmitter acetylcholine causes the depolarization of the motor end plate, initiating the nerve impulse to travel down the sarcolemma, through the transverse tubules and release calcium (Ca^{+2}) from the sarcoplasmic reticulum, which then binds to troponin and causing position changes in tropomyosin. Movement of the tropomyosin exposes active binding sites on the thin filament and allows for the linking of a myosin head, forming a cross-bridge attachment and causing the muscle fiber to contract.

To get the most force production out of a muscle, there needs to be the greatest amount of cross bridge attachment possible. Two methods of increasing cross bridge attachment are through additional motor unit recruitment and greater rate coding (Deschenes, 1989). In recruitment, the muscle recruits a greater number of motor units to increase force production (Henneman, Chapman, Gillies, & Skinner, 1974). Type IIx and IIa muscle fibers are found in large motor units, meaning, when stimulated, many muscle fibers are activated. However, larger motor units require the soma of the motor neuron to receive a higher rate of stimulation per second to become recruited (Brooks, Fahey, & Baldwin, 2005). In addition to this, rate coding involves increasing the stimulus rate to augment force production until the muscle reaches tetanus (Deschenes, 1989). By increasing the rate of action potentials to the neuromuscular junction of the muscle, Ca^{+2}

is pumped out of the sarcoplasmic reticulum faster than it can be re-sequestered leading to an accumulation of Ca^{+2} , exposing more binding sites on the thin filament and leading to further cross bridge attachments, ultimately increasing the force of the muscle contraction (Brooks et al., 2005).

When considering fatigue, it is important to note that it can be related to any number of impairments in this process. Nicol and Komi (2011) emphasize this notion deftly by saying that potential sites of impairments can be any one link in the long chain from the voluntary motor centers in the brain to the contractile filaments in the individual muscle fibers. This is also supported in the principle of task dependency, which states that there is no single cause of fatigue and the dominant mechanism is specific to those processes that are stressed during fatiguing exercise (Barry & Enoka, 2007). In the course of determining what causes these impairments, scientists tend to classify fatigue into two separate categories: peripheral fatigue and central fatigue.

Peripheral fatigue, also referred to generally as muscle fatigue, occurs within the muscle itself and can be further broken down into impairments at the transmission level (made up of the neuromuscular junction, muscle membrane, and sarcoplasmic reticulum), and at the contractile level, or sarcomeres themselves (Asmussen, 1979). Research on peripheral fatigue has documented that fatiguing exercise can lead to a decrease in the amount of Ca^{+2} released from the sarcoplasmic reticulum (Green, 1997; Abbiss & Laursen, 2005), leading to a reduction in force. The decrease in the amount of calcium released is also correlated to a reduction in Ca^{+2} reuptake from the sarcoplasm to the sarcoplasmic reticulum, which leads to an increase in muscle relaxation time and reduces force production (Hill, Thompson, Ruell, Thom & White, 2001; Abbiss & Laursen,

2005). There is also research to indicate that during a fatigued state, a lowering of the resting membrane potential at the sarcolemma due to an inability to restore sodium and potassium gradients before the next neural impulse causes muscle fibers to have a diminished response to electrical stimulation (Green, 1997; Abbiss & Laursen, 2005).

Central fatigue, or neural fatigue, occurs within the central nervous system and is related directly to a decreased activation of alpha-motor neurons responsible for muscle contraction. As with peripheral fatigue, central fatigue can manifest itself in a variety of forms and locations. As Abbiss and Laursen (2005) note in their review of literature concerning fatigue during endurance cycling, there are a number of studies that indicate increases in neurotransmitter concentrations in the brain during prolonged exercise lead to a decreased ability to recruit motor units. Research by Pinniger, Steele, & Groeller (2000) and St. Clair Gibson, Lambert, & Noakes (2001) assert that decreases in the firing frequency of motor neurons, combined with an increase in muscle fiber relaxation time due to Ca^{+2} imbalances, lead to a decrease in muscle force, further serving as a protective mechanism to prevent muscle injury during prolonged exercise. Additionally, the muscle's diminished response to electrical stimulation not only occurs at the sarcolemma as mentioned above, but also occurs on the alpha-motor neuron, caused by the lowered resting membrane potential prior to the neural impulse (Green, 1997; Abbiss & Laursen, 2005).

As much of the work of a catcher relies upon the need to spring up from the crouch position rapidly, there is a high necessity for muscles of the lower body to be able to respond to neural stimulation and create force in a short period of time. Likewise, infielders and outfielders also need to respond quickly to a play unfolding on the field

before them. The ability to accelerate rapidly, termed rate of force development (RFD), is highly sensitive to the effects of central and peripheral fatigue and is a useful measure of monitoring fatigue levels in athletes (Suchomel & Bailey, 2014). The effects of central and peripheral fatigue, with its lessening of alpha-motor neuron activation or diminished response to muscle stimulation, can have a detrimental effect on the performance of these athletes. Therefore, it is necessary to monitor the effects of fatigue on a regular basis throughout the season and provide adequate rest when a player is demonstrating diminished skills. Methods of monitoring fatigue will be discussed in greater detail later in this review; however, a description of the types of muscle action that lead to force production is needed first.

The Stretch-Shortening Cycle

Muscle contraction can be separated into three different actions: eccentric, concentric, and isometric (Komi, 2011). During eccentric actions, the muscle actively resists being lengthened while an outside force is greater than the force within the muscle. Often, eccentric contractions act as a braking force, decelerating a movement. In a concentric movement, the muscle shortens and the muscle tension is great enough to overcome the resistance to shortening. Isometric contraction occurs when muscle tension is equal to the resistance and the muscle does not change length. Normal movements such as running jumping, throwing and hitting are created using a progression of moving between eccentric and concentric actions and the sequence of these actions is termed the stretch-shortening cycle. The stretch-shortening cycle is defined as an eccentric muscular action followed by a concentric muscular action (Wilson, Elliott, & Wood, 1991).

It has been suggested that the stretch-shortening cycle can be classified as fast or slow, in reference to the speed of the contraction time and amount of angular displacement in the hips, knees and ankles. Depending upon the length of coupling time between eccentric and concentric phases, or the amortization phase, elastic energy is generated by the stretch of either muscle fibers or tendons. Fast stretch-shortening cycles are considered to be <0.25 seconds and have small angular displacements (Schmidtbleicher, 1992). Due to the short amortization phase, it is generally believed most of the shortening involved in this action takes place in the tendinous tissue rather than the muscle, which undergoes a more isometric contraction (Wilson & Flanagan, 2008). On the other hand, a longer (>0.25 second) duration of the amortization phase and greater angular displacement can be categorized as a slow stretch-shortening cycle (Schmidtbleicher, 1992). In this condition, the stretch occurs mainly within the muscle, activating muscles spindles and releasing stored elastic energy while also increasing recruitment of additional motor units, resulting in an augmentation of force production during the concentric phase of the movement.

The augmentation, or potentiation, of the stretch-shortening cycle improves the mechanical efficiency of the muscles by reducing the amount of energy required to perform the movement. With more stretch of tendinous tissue during fast stretch-shortening cycle movements, the energy demand for muscles involved is less. However, as the length of the amortization phase increases, there is a reduction in the amount of force generated as the stored elastic energy begins to dissipate as heat. Wilson, Elliott, & Wood (1991) demonstrated that elastic energy seems to have a half-life of approximately 0.85 seconds and a pause of four seconds prior to the concentric movement would negate

any stored elastic energy generated by the eccentric movement. In response, the muscles must use a greater amount of energy to replace the force that had dissipated, decreasing muscular efficiency. During a fatigued state, movements are less efficient, necessitating greater metabolic demands to achieve the required force output. This, in turn, reduces metabolic energy stores within the body and cause fatigue levels to further increase.

The amount of stiffness ($\Delta\text{force}/\Delta\text{length}$) within a muscle or tendon also plays a role in the generation of elastic energy during contraction. Muscle stiffness can be likened to the stiffness of a rubber band when stretched. If stiffness is high, there is a large increase in the amount of tension generated; when stiffness is low, the tension response to the stretch is correspondingly small (Edman, 2003). Yet, in addition to the contribution from the elastic properties, muscle or tendon stiffness is associated with input of stretch reflexes activated by feedback from muscle spindles during the eccentric component of the stretch-shortening cycle (Komi, 2011). It has been demonstrated that in fast stretch-shortening cycles, the amount of stiffness in the muscle increases (Wilson & Flanagan, 2008), leading to a greater generation of elastic energy in the muscles. However, muscle stiffness is negatively impacted by fatigue, as increased Golgi tendon organ activation from the stretch reflex acts to protect the muscle or tendon from injury (Edman, 2003).

Monitoring Fatigue through Physiological Measures

While ballistic movements involved in baseball like running, throwing, and batting, all utilize the stretch-shortening cycle, these movements provide challenges to measuring fatigue levels in baseball specific skills, with time and space concerns for testing being the most prevalent. However, vertical jump performance has been

frequently used across a multitude of sports as it allows sports scientists and strength coaches to analyze athletes' stretch-shortening cycle in quick and reliable manner. Numerous studies have demonstrated that reduced vertical jump performance following exhaustive exercise is an indication of a decrease in stretch-shortening performance and the development of neuromuscular fatigue (Horita, Komi, Härmäläinen, & Avela, 1999; Komi, 2000; Coutts, Reaburn, Piva, & Murphy, 2007; Freitas et al., 2014). While baseball does not utilize vertical jumps during play as much as other sports, such as basketball, using a vertical jump test as a measure of analyzing the stretch-shortening cycle can provide useful information that can be applied to running, throwing and batting movements. Additionally, the information gleaned during vertical jump testing is more related to the physiologic and neural responses of the muscles to a stimulus and can be translated among activities and quadrants of the body.

Three types of vertical jump measurements are commonly used to monitor fatigue: the countermovement jump (CMJ), the squat jump (SJ) and the depth jump (DJ). A CMJ begins with the athlete in a standing position, bending their knees to a self-selected depth followed immediately by jumping vertically (Komi & Bosco, 1987; Young 1995), utilizing eccentric, a very brief isometric, and concentric movements of the lower limbs to produce the vertical jump. Young (1995) notes, due to the longer period of time that occurs during the lengthening-shortening contraction, the CMJ should be considered a measure of slow stretch shortening ability or the reactive strength of the lower body (Young, 1995). In contrast to the CMJ, the SJ is a purely concentric movement, eliminating the eccentric phase and removing the contribution of the elastic components of the muscle and spindle reflex by pausing in the middle of the movement, thereby

testing the concentric strength of the leg muscles (Young, 1995). During a SJ, the athlete begins in a stationary squat position, often with a near 90-degree bend in the knee joint, though some researchers allow athletes to self-select a squat depth. Typically, after maintaining this position for at least three seconds, the athlete then springs up maximally (Komi & Bosco, 1987; Young, 1995). Finally, DJs differ from CMJs and SJs by actively engaging the stretch-reflex potentiation, in theory increasing the rate of force development. DJs also serve as a way of assessing muscle stiffness, with high stretch velocities reached in the early contact phase being sufficient for muscle spindle afferent activation (Komi, 2003). In a DJ, the athlete starts by standing on a step or box of a pre-selected height (30, 45, or 60 cm depending on jump ability of the athlete) and drops directly down onto the ground. Upon contact, the athlete then rebounds rapidly, aiming for maximal vertical height with as little ground contact time as possible (Komi & Bosco, 1987; Young, 1995). With the rapid rebound after ground contact typically in the range of 0.20-0.25 sec, a DJ can be considered an example of utilizing the fast stretch-shortening cycle.

Since the original use of vertical jump performance as a measure of explosive power by Komi and Bosco (1978), countless research studies have utilized these types of jumps to assess athletic ability, identify athletes' strengths and weaknesses, and monitor neuromuscular fatigue. Realizing that CMJs and SJs had been used as a testing measure for three decades without being validated, Markovic, Dizdar, Jukic, and Cardinale (2004) completed a study to conclude that CMJs and SJs, when measured by a contact mat and digital timer, were the most reliable in assessing explosive power in lower limbs when compared to other commonly used vertical and horizontal jump tests. Cormack, Newton,

McGuigan, and Doyle (2008) also tested multiple variables of the single CMJ and determined that it possesses both a high intraday and interday reliability. Further research has indicated that DJs are a valid way of predicting sprinting ability (Bissas & Havenetidis, 2008) and as a measure of monitoring neuromuscular fatigue in youth soccer players during tournament play (Hamilton, 2009).

Squat jumps, countermovement jumps, and depth jumps have all been modified into several testing protocols to determine individual variables as they relate to sport performance. The reactive strength index, the flight time: contraction time ratio, and the eccentric utilization ratio each have been demonstrated on numerous occasions to provide information to sports scientists and coaches regarding the function of the stretch-shortening cycle of athletes across a variety of sports. Each testing method will be discussed in greater detail in the following sections.

Reactive Strength Index

Reactive strength can be defined as the ability to change quickly from an eccentric to a concentric contraction (Young, 1995). As mentioned earlier, the shorter the amortization phase, the greater the amount of elastic energy can be used for optimal performance. There is also research to demonstrate that during very fast eccentric actions, additional myosin cross bridging takes place, generating a greater amount of force than a concentric-only movement (Linari et al., 2004). In order to measure the explosiveness of a movement, a measure of reactive strength was developed to allow coaches to gauge athletic ability. Titled the reactive strength index (RSI), this ratio is derived from the vertical height achieved following a DJ divided by the time spent on the ground (contact

time) developing the forces required for the jump (Logan, Fornasiero, Abernethy, & Lynch, 2000).

The RSI serves a dual purpose: it can be used as a training tool to help athletes develop plyometric movement at a faster rate or used as a method of monitoring training and performance volumes. Flanagan and Comyns (2008), in an article discussing the benefits of using the RSI as a training instrument in improving athletes' fast stretch-shortening cycles and maximal velocity, recommend that strength coaches and sports scientists use the RSI to examine contact times during plyometric exercises and determine where the athlete needs to focus their training. If ground contact time is greater than 0.25 seconds, the coach should first confirm that the subject is using the correct step height for their jumping ability, and then instruct the athlete to be more explosive and decrease their contact time by limiting bend of the knees and ankles, generating more muscle stiffness and initiating a greater stretch reflex. As well as monitoring contact time, the coach or sports scientist should also be monitoring jump height (frequently calculated from flight time measured by a contact mat or force plate) so that the athlete is not sacrificing jump power in order to achieve a faster contact time.

McClymont and Hore (2004) were the first to use the RSI as a method of investigating the effects of plyometric training. Testing elite rugby players prior to and following conditioning training, the authors discovered that there was a significant decrease in RSI at each of three step heights tested (15, 30, and 45 cm). While the results did not support their expected hypothesis and it was speculated that high training volumes near the time of data collection might have negatively influenced the RSI scores, they were able to deem the RSI as a useful tool in monitoring athletes' reactive strength.

Their findings also were an early indication that fatigue may be identified by use of the RSI following physical training. Later, Flanagan, Ebben and Jensen (2008) conducted a reliability study and found that the high repeatability of the RSI demonstrates the usefulness of the index for a coach or researcher who was assessing a large number of athletes at once.

Further research has continued to support the use of RSI as a valid measure of monitoring reactive strength and power for other purposes. For example, Srinivasan et al. (2013) used the RSI to conduct a comparison of athletic ability between playing positions on a high school baseball team. They concluded that there was little variation in athletic ability among positions on the baseball field, though they speculated that this was related to the similar levels of physical and athletic maturity in these players and encouraged future work to be conducted on athletes of higher skill levels. Beattie and Flanagan (2015) also used the RSI as a method of tracking neuromuscular fatigue in elite junior rugby players throughout an 8-week international tournament schedule. In this analysis, the authors determined that both RSI and contact time demonstrated acceptable reliability from trial-to-trial and day-to-day. However, the test lacked the sensitivity to determine changes in a group setting. Instead, the authors recommended that RSI be used to assess neuromuscular changes on an individual basis (2015).

Flight Time: Contraction Time Ratio

While the RSI has been successful in monitoring neuromuscular changes in athletes, it received criticism regarding the fact that it is limited to the DJ as the only plyometric exercise that can be used (Ebben & Petushek, 2010), as only the DJ incorporates an identifiable ground contact time used in the calculation. Instead,

Cormack, Newton and McGuigan (2008) created a method of monitoring neuromuscular changes throughout an Australian Rules Football (ARF) season that did not require a DJ. Focusing on flight time (FT) and contraction time (CT) during a CMJ, the authors identified these two variables as measures of neuromuscular status and utilized the ratio between FT and CT (FT:CT). In this equation, CT represents the combined time from the initiation of the countermovement until the subject leaves the force plate. When observing fatigue levels following a single ARF match, they concluded that FT:CT was sensitive enough to demonstrate a significant decline in neuromuscular status in elite ARF players up to 48 hours post-match. A follow-up study by the same group (Cormack, Newton, McGuigan, & Cormie, 2008) encompassing an entire ARF season similarly found that FT:CT decreased as the ARF season progressed, indicating the development of acute low-frequency neuromuscular fatigue.

Since these studies (Cormack, Newton and McGuigan, 2008; Cormack, Newton, McGuigan, & Cormie, 2008), FT:CT has been used frequently as a measure of neuromuscular fatigue in a variety of sports, though it has also been referred to as RSI_{mod} (Ebben and Petushek, 2010). RSI_{mod} is determined using vertical jump height divided by the time to take off (the time to complete the combined eccentric and concentric movements), which is similar to CT in the FT:CT ratio. Additionally, as vertical jump height is derived from flight time, the end result is that these two equations can be used interchangeably. For the purpose of consistency, FT:CT will be used throughout the remainder of this review when discussing this measure. Seeking to assess reliability for FT:CT, Ebben and Petushek (2010) tested 49 collegiate male and female athletes with five plyometric exercises, including unweighted CMJs, tuck jumps, the single-leg jumps,

SJs and weighted CMJs. They found that FT:CT displayed high reliability for all of the plyometric exercises tested and demonstrated no gender differences, allowing it to be used as a measure of explosiveness and the ability to quickly develop maximal force (Ebben & Petushek, 2010).

Several studies have continued to look into the reliability of FT:CT as a measure of explosive performance. Suchomel, Bailey, Sole, Grazer, & Beckham (2015) tested the explosive capability of 106 Division I collegiate athletes during loaded or unloaded CMJs. In the analysis, the investigators detected strong correlations between FT:CT and the rate of force development in unloaded and loaded conditions ($r = 0.56$ and $r = 0.56$ for men, $r = 0.66$ and $r = 0.69$ for women), supporting the notion that a larger rate of force development will lead to a higher vertical jump height, increasing FT:CT. Further, the authors determined there were moderate to large relationships between FT:CT and other force-time characteristics such as peak force and peak power, which could be used in the development of strength training programs (Suchomel, Bailey, Sole, Grazer, & Beckham, 2015).

There has also been some research in the comparison of FT:CT values among sports. Suchomel, Sole, Bailey, Grazer, & Beckham (2015) compared six Division I collegiate sports teams to examine the differences in FT:CT, as well as the independent components of jump height and time to take-off. Of the teams studied, it was concluded that men's baseball and soccer generated the greatest FT:CT values, followed by women's volleyball, men's tennis, women's soccer and women's tennis (Suchomel, Sole, Bailey, Grazer, Beckham, 2015).

With the work of Cormack, Newton, McGuigan, & Cormie (2008) demonstrating that FT:CT can detect the development of neuromuscular fatigue across a competitive season, more research needs to be completed to show that this is true among different sports. With its uncomplicated testing protocol involving a force plate and a willing group of subjects able to perform CMJs, the FT:CT ratio is considered a simple, reliable and effective method of monitoring fatigue levels in athletes over a training season.

Eccentric Utilization Ratio

In 2006, McGuigan, Doyle, Newton, Edwards, Nimphius, and Newton proposed an alternative vertical jump protocol that compared slow stretch-shortening cycle ability to concentric strength in the lower body. Termed the eccentric utilization ratio (EUR), this calculation divided the jump height or peak power output during a CMJ with the corresponding SJ variable ($EUR = \text{countermovement jump} / \text{squat jump}$). Previous work by Balsom (1994) investigated the relationship of jump performances in the SJ and CMJ, but until McGuigan et al. (2006), no further work had been done to investigate that relationship across a multitude of sports. In their study, the EUR values of 142 male and female elite athletes across five different sports (rugby union, ARF, softball, field hockey and soccer) were compared. It was determined that athletes in soccer, rugby union, and ARF exhibit higher EUR values, supporting the greater dependence on the stretch-shortening cycle during these sports. The authors also concluded that there were some changes in EUR that were dependent upon the training phase. Field hockey players demonstrated a significantly greater EUR immediately prior to the start of the competitive season than during offseason testing.

Doyle (2005) investigated the relationship between SJ performance and performance during CMJs. His study used 11 elite youth rugby union players and tested their CMJ and SJ jump height and peak power four times throughout a 34-week strength training program. The results demonstrated a clear increase in EUR from an improved CMJ performance (as calculated with both jump height and peak power) as the training progressed.

Both Doyle (2005) and McGuigan et al. (2006) utilized highly trained athletes for their studies and along the way, demonstrated that the EUR is sensitive to changes in training status for this level of skill. In 2009, Hawkins, Doyle and McGuigan sought to determine if EUR is able to determine training status in untrained college males using different methods of resistance training. In comparing three training groups (plyometrics, weight training, and weight lifting) over 9 weeks, it was determined that there were no significant differences between groups in jump height or power performance at any testing phase. However, there were some trends indicating a change in EUR for jump height and power, suggesting that a longer training period may have shown a greater significance. The authors concluded that more work needs to be done to determine the sensitivity of EUR on untrained individuals (Hawkins, Doyle & McGuigan, 2009).

Monitoring Fatigue through Subjective Questionnaires

There are many subjective measures that allow athletes to report fatigue levels. Some measures, such as the Session Rating of Perceived Exertion (Session RPE) (Foster, 1998) and the Perceived Recovery Scale (PRS) (Laurent et al., 2011), are simple one question scales that allow the athlete to estimate how hard they feel they worked during a training session or fatigue estimates after a recovery period, respectively. Another

method, the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) (Kellman & Kallus, 2001) is extremely detailed and asks the athlete about various aspects of their recovery. However, the challenge with the surveys mentioned is that they run the risk of being either too simplistic (with the one question design for the PRS and the Session RPE) or being too time-consuming and involved for athletes to complete on a regular basis, such as the 77-question RESTQ-Sport. Appropriate surveys need to be long enough to get a true understanding of the athlete's physical and mental fatigue levels, but condensed so that they can be completed quickly and on a fairly regular basis. Suchomel and Bailey (2014) suggested that it is beneficial for sports scientists to use a tracking questionnaire at a minimum of once per week throughout the season to monitor fatigue, but sports scientists should also be aware the amount of distraction to the athlete caused by the completion of surveys and questionnaires. Halson (2014) confirmed this notion by emphasizing that the frequency of questionnaire administration and length of questionnaires should be considered to avoid what she termed as "questionnaire fatigue".

With these challenges in mind, various surveys were assessed for use in this project, and one was determined to be detailed enough in using a minimal number of questions that a true gauge of fatigue would be gathered in a quick and timely manner. Based off of a series of distress symptoms found in military personnel after intense physical training, the Training Distress Scale (TDS) (Grove et al., 2014) is comprised of 19 questions referring to individual responses related to general fatigue, muscle soreness, emotional status, sleep disturbances, concentration difficulties and appetite changes that have occurred over the past 48 hours. In the initial publication, the authors conducted three phases of a study to validate the TDS as a measure of short-term training distress

and performance readiness. During the first two phases, subjects assigned to a treatment group were asked to complete increasingly intense exercise sessions as the testing sessions continued, while a control group maintained the level of intensity. In both cases, TDS scores of the treatment group increased as performance quality decreased throughout testing, with the control group maintaining TDS scores. In the final phase, the authors compared TDS scores throughout a two-week period leading up to and the subsequent performance in a swimming competition. It was determined that those athletes who had lower TDS scores leading up to the competition performed better than those with higher TDS scores in the weeks' prior. With the validation of the TDS by Grove et al. (2014), as well as the succinct nature that the survey encompasses mental and physical manifestations of fatigue, it was concluded that the TDS would be the optimal questionnaire for monitoring fatigue levels in collegiate baseball players.

Previously Completed Research Concerning Fatigue in Baseball

While baseball is a popular sport in the United States, Japan and Central America, until recently, there has been very little research published on the fatigue in baseball, particularly due to the difficulty of finding effective methods of monitoring players' fatigue levels throughout a season. However, the research that has been completed in this area is promising and serves as an encouragement to continue exploring this topic.

In 2013, Kutscher, Song, Wang, Upender and Malow investigated the effects of fatigue on batting performance throughout Major League Baseball seasons. Comparing records from 2002 through 2011, the authors specifically observed the number of times batters chose to swing at pitches located outside of the strike zone as the seasons progressed. It was concluded that, in each season, as constant travel and few days off

accumulated, the players' strike zone judgment worsened and they were more likely to swing at pitches that they might not have during the early phases of the study. Further, the degree of performance decline was greater following the 2005 ban on stimulant drugs in Major League Baseball (Kutscher et al., 2013). While not much can be done to change the amount of travel or the long seasons that major league players face, the implications from this analysis has influenced several major league teams to begin monitoring different aspects of fatigue throughout the season (Berra, 2015; Costa, 2015). Further, these conclusions can also be applied to collegiate baseball seasons, with long bus rides to face distant opponents, frequent double-headers, and the added stress of academics, family, and personal life.

It is common practice for a baseball team to have a squad of five starting pitchers (called the starting rotation), who alternate between starting a game every four or five days (Bradbury & Forman, 2012). Further research has been conducted to analyze the effects of fewer rest days for baseball pitchers. Potteiger, Blessing, and Wilson (1992) researched the physiological responses to varying days between starts and how it impacted a pitcher's performance. In their study, subjects were asked to complete several simulated game scenarios by throwing 100 pitches with three days' rest between sessions, expanding the time to four days of rest, and decreasing the amount to two days of rest. By analyzing blood samples for creatine kinase and lactate dehydrogenase, enzymes which are attributed with skeletal muscle damage after intense exercise activity, the investigators concluded that having four days or two days of rest between pitching activities did not significantly influence muscle enzyme activity. Additionally, the level of soreness reported by the athletes also did not increase significantly as the period of rest

was reduced; however, pitching velocity decreased as the amount of rest time decreased. With the definition of fatigue encompassing any decline in the ability to exert muscle force or power (Bigland-Ritchie & Woods, 1984), the authors concluded that it was possible that these pitchers were suffering from neuromuscular fatigue to a greater extent when they had fewer days of rest between starts (Potteiger, Blessing, & Wilson, 1992). Additionally, as pitchers depend on velocity and movement of the baseball to keep batters off balance, a decrease in velocity could lead to a poor pitching performance, impacting the team's chance of winning the game.

Considering how little research there is on the role of fatigue in the sport of baseball, there is an even greater lack of information regarding the effects of fatigue on position players on a baseball team, rather than just the pitcher. Nimphius (2011) completed a study which recorded jump height and FT:CT during a CMJ on a force plate in order to monitor the neuromuscular fatigue experienced by 19 amateur baseball players during a national tournament. It was determined that subjects of this study displayed a marked decrease in FT:CT ratios during the third, fourth and fifth games of the tournament. However, when provided with an almost 24-hour recovery time between games five and six, players were able to recover enough to achieve FT:CT ratios near pre-tournament levels. It was also concluded that FT:CT was more sensitive to changes in neuromuscular fatigue levels than jump height, which demonstrated some marked changes over the course of the tournament, but not to a single or multiple games (Nimphius, 2011).

Bailey, Suchomel, Beckham, Sole and Grazer (2014) conducted a study to determine if there were differences in FT:CT values between baseball pitchers and

position players during loaded and unloaded CMJ. It was determined that position players had statistically significant greater FT:CT values than pitchers during loaded countermovement jumps. These findings are likely related to an observation that position players tend to have a greater amount of strength in their lower body, contributing to larger FT:CT values and a more efficient stretch-shortening ability (Bailey, Suchomel, Beckham, Sole & Grazer, 2014). Similarly, Srinivasan et al. (2013) compared RSI values of pitchers, catchers, infielders and outfielders on a high school baseball team. However, no identifiable difference was observed between positions on the team and the authors speculated this was because the athletes involved in the study all had similar training levels and experience.

Future Studies in Baseball

As indicated with the previous section, there are still areas of research within this field that need to be filled. The most glaring research question is a further comparison of fatigue levels among players on a single team, separated by position. With the Bailey et al. (2014) study, as well as that conducted by Srinivasan et al. (2013), this area has been touched upon briefly. However, Bailey et al. (2014) chose to compare fatigue levels between position players, who primarily use their lower body in response to quick plays in the field, to pitchers, who are much more upper body dominant in their performance. A further comparison of position players, separated by infield and outfield positions, should demonstrate more clearly whether fatigue impacts positions on a baseball team in different manners.

Additionally, given that the catcher on a baseball team is in constant motion between plays and has the potential to have developed a greater amount of fatigue

throughout a single game or season than other players on the team, further research should be conducted on catchers as the primary subject, with an analysis of whether providing catchers with more days of rest between catching games would show a decrease in fatigue levels. This could be analogous to the use of a pitching rotation, with starting pitchers receiving four or five days of rest between starts. It would be an interesting concept to determine if there is a basis for developing a catching rotation for baseball teams as well.

Finally, further investigations should be conducted to compare any increase in fatigue indicated by the monitoring suggested in this literature review relates to a decline in baseball performance. This could be evaluated using player offensive and defensive statistics, with a focus on batting average and errors committed during play. Measurements of fatigue in this research area should be a combination of physical measurements, such as the FT:CT ratio or eccentric utilization ratio, and use of questionnaires like the TDS to monitor both mental and physical fatigue. Additionally, questionnaires monitoring sleep patterns of the athletes could also provide a good understanding of the fatigue that might be accumulating over the season.

Conclusion

At the present time, there has been little investigation into the accumulation of fatigue of catchers and position players on a baseball team. With long seasons and few rest days, the development of fatigue can play a significant role in the decline of a player's offensive and defensive performance. From here, it is recommended that future research be conducted to determine if there is a difference in the amount of

neuromuscular fatigue that develops based upon positional roles, as well as the effects of additional days of rest between performance on neuromuscular fatigue.

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