Visual Search Strategies of Elite Baseball Players During a Baseball Hitting Task

by

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Baseball batting is a cognitively demanding interceptive timing task that requires precision and power. Due to the quick duration of an at-bat, anticipatory visual cues and predictive eye movements are needed to have an accurate final fixation while initiating bat swing. Previous research has demonstrated expert hitters have superior dynamic visual acuity and superior visual search strategies. However, little research has examined the eye movement patterns and visual search strategies in an interceptive task. The purpose of this study was to examine the eye movement pattern differences in baseball players of varying skill levels and to observe changes in eye movements due to hit quality and pitch type. Sixteen participants with varying baseball playing experience were recruited (eight elite, eight sub-elite players) to perform a baseball hitting task. During the hitting task, participant's eye movements and fixation points were recorded using mobile eye tracking equipment. There were no significant differences in the time points of anticipatory eye shifts between the elite and sub-elite group. There was a significant negative correlation between the time point of the first anticipatory saccadic eye movement and hit quality [$r(12) = -.547$; $p = .043$] and a significant positive correlation [$r(12) = .651$, $p < .05$] for the average time lapse between the first saccadic eye movement and the last captured frame

in the known conditions for all participants. Overall, the results demonstrated the role visual search strategies in interceptive tasks.

Visual Search Strategies of Elite Baseball Players During a Baseball Hitting Task

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Chapter I. Introduction

The best hitters in Major League Baseball (MLB) only succeed in about 30% of their at-bats. The low amount of overall success in hitting a baseball is due to the extreme difficulty in the task. The average MLB pitcher can throw a baseball (9-inch average circumference) over 90 miles per hour (mph) from a mound 60.6 feet away, which is shortened by the delivery of the pitcher (Simon, 2019). A 90mph baseball takes around 400 milliseconds to leave the pitcher's hand and travel to the point of contact over home plate. Also, the batter must determine in that short amount of time whether to swing at the pitch or not. Baseball hitters need superior vision and motor coordination to hit a baseball successfully.

Dynamic visual acuity (DVA) is a person's ability to see a moving object through space. DVA is a vital skill for athletes in many sports, including baseball players, and has been frequently studied in interceptive timing tasks. Eye movement patterns are an important factor of DVA, since the eyes are tracking a moving stimulus. A baseball batting task requires strong DVA abilities since the objective is to hit a moving object in space. It has been shown that baseball players have superior DVA abilities than non-baseball players (Uchida, Kudoh, Murakami, Honda, & Kitazawa, 2012). While we understand that baseball players have superior DVA abilities, we do not understand the eye movement patterns and visual search strategies utilized in a complex DVA task like a baseball batting task. It is important to understand the eye movement patterns and strategies required to hit a baseball because it can improve developing, scouting, and training baseball players from a sensorimotor standpoint.

Baseball batting is a cognitively demanding task because the batter must see the baseball, extrapolate where it is going, decide whether to swing at the ball, and then successfully hit the ball. Researchers have looked at experts and non-expert baseball hitter's DVA and anticipatory visual fixations in vision tasks and found differences between the two groups. Expert baseball batters were superior in visuomotor tasks and had more efficient anticipatory visual search strategies than non-experts (Klemish et al., 2017; Nakamoto, Mori, Ikudome, Unenaka, & Imanaka, 2015; Sasada, Nakamoto, Ikudome, Unenaka, & Mori, 2015). These studies indicate that expert baseball players have a higher DVA skill level and more resourceful anticipatory visual fixations than novices, which may contribute to their ability to hit a baseball.

A limitation to these DVA studies is that most of the research looking at the DVA skills of baseball players have used visuomotor tasks that are not comparable to actual hitting tasks seen in a baseball game. Some researchers have measured the sensorimotor capabilities of baseball players using computerized sensorimotor tasks, such as the Nike Sensory Station (Burris et al., 2018; Klemish et al., 2017). A few studies have measured the DVA of baseball players using Landolt-C ring tasks (Palidis et al., 2017; Uchida et al., 2013). Researchers have also investigated DVA in baseball players using predictive visuomotor tasks dissimilar to a baseball hitting task (Fooken et al., 2016; Nakamoto et al., 2015; Takeuchi & Inomata, 2009). While all these studies have shown that more experienced baseball batters have higher DVA skill levels, it does not reveal how they use these abilities to hit a baseball accurately.

The interceptive timing tasks used while measuring eye movement have not been like a hitting task used by baseball players. Research has been conducted using interceptive timing tasks with tennis balls projected from a pitching machine rather than baseballs thrown from a live person (Fogt & Zimmerman, 2014). Other studies have utilized virtual reality hitting tasks that include moments of visual occlusion (Ranganathan & Carlton, 2007). Some previous research using interceptive timing tasks have employed pressing a button for the interceptive action (Nakamoto et al., 2015; Takeuchi & Inomata, 2009). Many studies measuring eye movements have utilized visual occlusion to analyze moments of the hitting sequence where visual cues are most important for hitting success (Gray and Cañal-Bruland, 2018; Higuchi et al., 2016). This research does not explain the eye movement patterns utilized to be successful in an interceptive timing task, but helped researchers understand which visual moments of the trajectory are most dependent for successful contact.

It is important to record the eye movements of baseball players as they track randomized high and low velocity moving objects, because it is similar to game-like hitting task. There have been a few studies that have had participants replicate a baseball batting task similar to a game-like hitting task while utilizing visual occlusion (Higuchi et al., 2016; Ranganathan & Carlton, 2007; Sasada et al., 2015). Each of these studies examined different aspects of vision such as pitch recognition ability, and dorsal versus ventral processing of vision. Also, the hitting tasks still had some discrepancies compared to a baseball batting task seen in a game. The participants in the Higuchi (2016) study were facing one type of pitch in a constant location (fastballs on the outer half of the strike zone). Participants in the study conducted by Ranganathan and Carlton (2007) performed a baseball hitting task in a virtual reality simulator to observe their ability to distinguish pitch types and anticipatory performance. However, the participant's vision was occluded during sections of the ball's flight path. Sasada et al. (2015) also had participants perform a coincident-timing task by swinging a bat or pressing a button at a high velocity baseball projection that changed colors during its flight path. The researchers wanted to see if expert baseball players could recall the color changes that occurred mid-flight, as well as their accuracy at interceptive timing in the visuomotor task. All three of these studies have shown the importance of visual cues in the pitching delivery and visual information during the first two-thirds of the ball flight path.

Although, these studies are examples of interceptive timing tasks used in research, they do not accurately represent a baseball batting task seen in games or practice. A baseball hitting task involves swinging a bat at a high velocity target, which is a more sensory motor demanding task than pressing a button or simply observing stimuli. Also, these studies have not recorded the eye movement patterns used during these baseball hitting tasks to measure sensorimotor differences between elite and sub-elite baseball players. Therefore, eye movement patterns and visual search strategies of baseball players have yet to be recorded and analyzed in a game-like batting task.

Importance of the Study

There are many aspects of visual search strategies, so it is important to analyze all eye movements involved in an interceptive timing task such as fixations, gaze error, saccades, and smooth pursuit. Past literature has shown that higher level baseball players display superior visual motor reaction time compared to lower level baseball players (Laby, Kirschen, Govindarajulu, & Deland, 2018) and smaller high-order optical aberrations (Kirschen, Laby, Kirschen, Applegate, & Thibos, 2010). Previous research has shown that differences in DVA can be seen between expert and non-expert baseball players in visuomotor tasks. However, we still do not fully understand the relationship between eye movement patterns and how they associate with hitting success. How do expert level baseball players move their eyes differently than non-experts while hitting? Also, between and within participants, what types of eye movement patterns and visual search strategies indicate successful hits? An area that has been lacking in research is the eye movements of baseball players employed during the baseball trajectory. There has been little research that has analyzed the eye movement patterns and visual search strategies of baseball players during baseball flight in a batting task.

Several practical implications could be derived from this study. First, understanding the eye movement patterns found in elite baseball players can help in evaluating baseball players at the college and professional level. A vast amount of resources is spent by colleges and professional baseball organizations to evaluate and scout players across the world. Scouts currently evaluate hitters by power (exit velocity from contact) and contact ability (amount of successful hits overall). However, finding gaze pattern differences between baseball players of different abilities can give scouts a whole new area to evaluate players. Scouts could evaluate players using eye tracking equipment to see the search strategies they use to track the ball and compare their eye movement patterns and visual search strategies with players at the highest level of play.

Hypothesis & Purpose

The purpose of this study was to find differences in eye movement patterns among baseball players of varying skill levels as they try to hit baseballs in a baseball batting task. Another purpose is to observe if there are distinct eye movement patterns relative to high- and low-quality hits in a baseball hitting task. A final purpose is to observe if there are differences in eye movement patterns between known and unknown pitch types. Previous research looking at the eye movement differences between expert baseball players and non-experts have had participants performing visuomotor or interceptive timing tasks that did not accurately represent a real baseball at-bat. Also, previous research has looked extensively at which visual segments of a baseball batting task are most important for hitting success using visual occlusion. However, research has not explained the relative eye movement patterns utilized during the baseball trajectory in a batting task. We hypothesize that the elite baseball players in this study will initiate their anticipatory eye movements sooner, have reduced overall eye movement, and have more successful hits than the sub-elite participant group.

Chapter II. Literature Review

Reaction Time & Sensorimotor Skill

Baseball batting is an interceptive timing task that challenges the full capabilities of humans due to the sensorimotor demands involved. Sensorimotor skill is the process of producing a motor response based on sensory information (stimulus). In baseball hitting, visual information, search strategies, and response selection are crucial aspects to succeed. There are many mechanisms involved in sensorimotor skills, but one simple way to evaluate sensorimotor skill is by reaction time. Reaction time is the amount of time needed to elicit a motor response from a stimulus. Donders (1868/1969) wanted to know the time required for people to mentally process and respond to a stimulus. He created a simple visuomotor task to measure response times in people, as well as other sensorimotor tasks that varied in complexity. The five participant's response time averaged 154 milliseconds (ms) for the task. Also, Donders found that the more complex sensorimotor tasks resulted in longer response times from participants. This groundbreaking study puts the difficulty of baseball hitting into perspective. A 90-mph baseball takes about 400 ms to reach home plate, and humans can elicit a simple response to a stimulus in around 150 ms. However, batting is not a simple sensorimotor task; the pitched ball varies in velocity, location, and movement with each pitch. The batter must determine if the pitch will be in the strike zone, the type of pitch, and initiate a swing within 400 ms. Slater-Hammel and Stumpner (1950) recorded the movement reaction time of baseball players swinging a bat at the onset of a visual stimulus. It took experienced baseball players an average of 210 ms to initiate the bat movement. Therefore, the time constraints on baseball batters in a hitting task is even tighter than in simple response reactions.

For almost 100 years, scientists have examined the visual abilities and sensorimotor skills of expert baseball players. In 1921, researchers Albert Johanson and Joseph Holmes performed an informal study on elite baseball player Babe Ruth where they analyzed his brain, eyes, ears, and muscle activity through a series of tests. Babe Ruth's eyes moved 12% faster on a simple sensorimotor task, and he performed well above average on several vision tests compared to the general population at the time. Winograd (1942) wanted to see the relationship between timing and vision with successful baseball batting in participants of various baseball experience. He did not find any significant relationships between vision measures and batting statistics. He observed that college varsity baseball players performed significantly better than non-athletes on the choice and directed timing tasks, and had superior binocular visual efficiency, visual efficiency of least efficient eye, stereopsis, near point fusion, near point lateral imbalance and simultaneous vision. Varsity baseball players had significant differences than rejected college athletes in directed timing, far point, lateral imbalance, and simultaneous vision tasks. This was one of the first studies that found visual acuity and response time differences between baseball players of different skill levels.

Adams (1965) progressed research on baseball batters by studying the influence of eye dominance and batting stance on hitting success. Unilateral (dominant eye and hand are the same) and cross-lateral (dominant eye and hand are different) baseball batter's hitting statistics throughout a season were compared with each other. The results showed that unilateral participants had a significantly higher on-base-percentage than cross-lateral participants. Unilateral participants that used an open batting stance (front foot further to outside than back foot) struck out significantly less than unilateral participants that used a closed stance (front foot further to inside than back foot). These results suggest that there is a relationship between eye dominance and batting stance with batting success. Eye dominance may influence batting stance, which impacts the initial starting point of eyes in the hitting task. Therefore, eye dominance may play a role in the visual search strategies used by baseball players.

Lucia and Cochran (1985) wanted to test if perceptual information can be extracted throughout a ball's trajectory. They ran an experiment using experienced fast-pitch softball players as participants. The participants performed a hitting task with their vision occluded in different thirds of the ball trajectory. After hitting 20 baseline pitches, participants hit 20 pitches in each of the three visual occlusion conditions. The participant's frequency of contact was significantly reduced when the middle third of the ball flight was blocked from view. The findings from this study suggest that there could be important DVA skills that need to be executed during the middle of the ball's flight path. Their study leads to a popular notion in baseball that suggests that elite baseball players can see the seam rotations of the baseball midflight, which allows them to recognize the pitch type. Hyllegard (1991) ran a study to see if a baseball's seam rotation during flight influenced pitch recognition. Experts and non-experts viewed a series of pitches from a video projector. The experts were significantly more accurate in recognizing the seam rotation than non-experts. However, the experts may have been using visual cues from the pitcher's mechanics to determine the type of pitch, which would lead to an accurate prediction of the seam rotation.

The two-streams hypothesis emerged suggesting that the brain processes visual information in two different streams, the dorsal and ventral streams (Goodale & Milner, 1992). The dorsal stream is the "where" pathway and it assists in the processing of spatial location; the ventral stream is the "what" pathway and it is engaged in the processing of visual recognition and identification. The theory can help explain visual cues necessary and unnecessary for baseball player's hitting success (Miller & Clapp, 2011). Sasada et al., (2015) conducted a study looking at the visual streams utilized by college and novice baseball players in a coincident timing task. Participants had to correctly intercept a projected visual target with two conditions, a button (uncoupled) or swing (coupled) response. Also, the visual stimulus would randomly change colors during some trajectories. Participants had to answer whether the color changed, and if so, what was the final color. The expert group displayed superior timing performance in the interceptive task. Yet, the expert group had significantly lower correct responses on ball color changes in the coupled response. These findings indicate that expert baseball players rely more on the dorsal stream in this interceptive timing task than non-experts since they were more accurate in their response timing. Therefore, expert baseball players do not utilize the ventral stream as much while performing this interceptive timing task in a coupled response. The coupled response task requires more dorsal stream processing, which is why the expert baseball players were significantly less accurate in color change answers. The results of this study suggest that certain visual information may be irrelevant in the success of hitting a baseball (color changes, seam rotations).

With the aforementioned studies finding reaction time and sensorimotor skill distinctions in higher level baseball players, researchers are now looking to measure sensorimotor capabilities of expert baseball players and correlate them with hitting statistics. Laby, Kirschen, Govindarajulu, & Deland (2018) analyzed the eye-hand visual-motor reaction time (EH-VRMT) in 450 professional baseball players using a EH-VRMT system, and how it related to their batting statistics. The researchers compared the batting statistics of the top 20% EH-VRMT scoring participants to the bottom 20% EH-VRMT scoring participants. The best EH-VRMT participants had significantly higher walk rate than the worst EH-VRMT participants (22%

difference) and swung at less pitches outside of the strike zone than the worst EH-VRMT performers (10-12% less swings).

Saccade Components

In order to examine the gaze patterns of baseball players in a hitting task, different kinds of eye movements must be understood. Multiple types of eye movements are involved in the DVA process. Saccades are one of the four basic types of eye movements. Saccade is used in terms of vision to describe the rapid, ballistic movement of the eyes from one visual fixation point to another visual fixation point (Purves et al., 2001). Saccadic eye movements are measured by amplitude, duration, latency, and peak velocity. Saccadic eye movements can be voluntary (controlled by the individual), or they can be involuntary (reactive to visual stimuli). Saccades are a vital aspect of understanding gaze patterns in sports with rapid moving objects like tennis, cricket, and baseball because they are the swiftest eye movements. Therefore, numerous researchers examining the DVA of baseball players have analyzed their saccadic eye movements in their studies.

Several characteristics are underlying saccadic eye movements that researchers measure. Saccadic eye latency is the time it takes from the appearance of a visual stimuli to the start of the saccade in response to the visual stimuli. Individuals with expert fast-ball sport experience have shown shorter latency times compared to participants in a normal population (Uchida et al. 2013; Zhang & Watanabe, 2005; Land &Mcleod, 2000). Many studies measuring the DVA abilities in baseball players by recording saccadic eye movements have utilized visual or visuomotor tasks that are unlike the hitting task seen in a baseball game. However, these studies have given us a better understanding of the saccadic eye movement characteristics displayed by athletes in visual and visuomotor tasks, which may translate to an actual baseball at-bat.

Uchida et al., (2013) analyzed the DVA of eight expert and eight non-expert baseball players wearing eye tracking devices while performing a visual task. Participant's eye movements were recorded as they tracked visual stimuli on a screen projection. Participants had to track Landolt-C rings as they moved horizontally across the screen at random velocities. Landolt-C rings are objects shaped like the letter "C", but the gap orientation can be at the bottom, top, left, or right side. Moving from the left or right side of the screen (participants told which side before each trial), the Landolt-C rings velocities ranged from 200 degrees per second to 900 degrees per second (with increments of 100 degrees per second in between), and it disappeared after the movement. Uchida et al., (2013) found that expert baseball players were significantly more accurate in their responses and had less mean retinal error when tracking the visual stimulus between 400-600 degrees per second. The expert group had significantly shorter saccadic latency times on all targets between 200 and 600 degrees per second. The results of their study showed that expert baseball players had superior tracking abilities (shorter latency, less mean retinal error) of targets that move at velocities comparable to a major league fastball. The shorter saccadic latency times found in skilled fast-ball individuals gives hitters more time to react with secondary saccades and predictive eye movements compared to the general population. There were no significant differences between expert and non-expert baseball player's response rate when their mean retinal error was similar. Therefore, expert's superior DVA ability in this study was attributed to more efficient eye tracking skill than image processing ability.

Baseball players are not the only athletes that have been observed to have shorter saccadic latencies than non-athletes. Ceyte et al. (2016) tested saccadic latency and accuracy in fencers, gymnasts, swimmers, tennis players, and non-athletes using eye tracking equipment.

They found significantly shorter latencies in all athlete groups compared to the non-athletes. Fencers and tennis players showed more accurate latency in visual targets in a random sequence compared to athletes in the gymnast and swimming groups; this may be due to the quick reactive actions required in fencing and tennis that is not as relevant in sports such as gymnastics and swimming. However, there was no significant differences in latency times between the athlete groups. The elite group in this study should have shorter eye latency times and higher latency accuracy compared to the sub-elite group.

The amplitude of saccadic eye movements is the overall distance covered by the saccade, and it is typically measured in degrees. Many studies have found that more skilled baseball players have lower saccadic amplitudes than less skilled baseball players (Kato & Fukuda, 2002; Palidis et al., 2017). Reverse saccades are saccadic eye movements that travel in the opposite direction of the visual stimulus, which impacts overall saccadic amplitude. Palidis et al. (2017) found that younger expert baseball players used reverse saccades more frequently when trying to track high velocity moving targets. The reverse saccades used by the younger expert hitters resulted in less effective tracking of the visual stimulus. The researchers theorized that reverse saccades were used to intercept the target before it traveled back to its fixation point. This occurrence is the equivalent of a batter moving their visual focus from the baseball to their ideal contact point in front of the plate, and then back to the baseball. Therefore, reverse saccades result in higher saccadic amplitudes over the course of a pitched baseball. Participants in the elite group should have smaller saccadic amplitudes than the sub-elite group because they will be using less reverse saccadic eye movements, which has been recorded in less experienced baseball players. Thus, saccadic duration should be smaller in the elite baseball group compared to the sub-elite groups since they are making less saccadic eye movements during the baseball trajectory.

The peak velocity for a saccade is the top speed of the eyes reached during the saccade. The faster and farther range a visual stimulus is moving through space, the higher peak velocity will be required from the eyes to pick up the target. Expert baseball players have displayed higher saccadic peak velocity while following moving targets compared to a non-expert baseball group (Uchida et al., 2013). Kato & Fukuda (2002) found that novice participants had higher eye velocities while watching video simulations of pitchers throwing at them compared to participants in an expert baseball group. However, the Palidis et al. (2017) study revealed that participants had superior perceptual performance when the peak velocity of their eye movements was lower. They found that participants with lower peak velocity in their saccades had less minimum eye position error, suggesting that higher peak velocities in saccades resulted in higher minimum eye position error. Although, the results from this study may be due to the two-dimensional horizontal motion of the moving targets that do not accurately represent a pitched baseball moving through a three-dimensional space. Participants in our elite group should have higher peak velocities during the pitch sequence than subjects in the sub-elite group due to the elite participants having more experience with higher velocity moving targets in a three-dimensional space.

Microsaccades are small involuntary eye movements that move similarly to saccades. Due to microsaccades being involuntary, these movements could indicate where the mind is unconsciously focusing, although gaze may be focused in a different location (Piras, Raffi, Lanzoni, Persiani, and Squatrito, 2015). Piras et al tested microsaccade abilities in table tennis experts and non-expert table tennis players using eye tracking equipment. Participants were presented a video of a ping-pong table and opposing player on the other side from a first-person view. Subjects had to focus on a fixated visual target located on the chest of the opposing player through the entire duration of the video. After a brief pause, a ping-pong ball was served to the opposing player on the video screen to which they reacted by hitting back the ball. The video ended after the opposing player contacted the ball. Subjects had to determine as quickly as possible which side of the table the ball would travel to once the opposing player contacted it. The expert table tennis group correctly predicted which side of the table the ball would travel with more accuracy and significantly faster response times compared to the non-expert group. In this study, the elite baseball group may have more successful hits than the sub-elite group even when their final fixation is not in an accurate location, and this may be due to superior microsaccade abilities.

Vestibulo-ocular movements

Vestibulo-ocular movements assist in keeping the eyes stable relative to the external world, so it accounts for head movement. These vestibulo-ocular reflexes help visual images stay on the surface of the eye's retina as head position varies (Purves et al., 2001). While early studies on baseball hitting focused on the motor response component of batting, Hubbard and Seng (1954) conducted one of the first experiments examining the visual-perception components of hitting. The researchers analyzed the head and eye movements of baseball players in a game setting by recording the batting task with cameras and examining the head and eyes of participants in the pictures frame by frame. The participant's recorded swings showed that their heads were fixated while they tracked the ball with their eyes. Also, the researchers observed the head movements of baseball players during games and recorded whether gross head movements were used to track the ball. In the live games, the researchers observed that 99.6% of participant's swings involved little to no head movement prior to swing initiation. The final major finding from this study was that elite batters' eyes went from near to far focus around the point of convergence. The finding suggests that expert batters do not track the baseball to the point of bat to ball contact, and that head movement is minimal among high level baseball batters.

Recently, Fogt and Persson (2017) conducted a pilot study looking at the horizontal head and eye rotations of participants during a baseball hitting task. The researchers recruited two participants that played baseball at the collegiate level, and still actively participated in baseball league play. The study was conducted at an indoor batting cage and utilized a pitching machine that projected tennis balls. The eye movements of participants were recorded using infrared video-recording goggles. Head movement was monitored using an inertial sensor head tracker device. The experiment had two conditions. The first condition, participants viewed 50 pitches, and they were instructed to intentionally not swing at the pitches. The second condition, participants were instructed to try and hit the balls, which was a total of 40 total in this condition. One of the researchers graded hitting performance to associate eye and head movement behaviors with successful hitting. The researchers did not find any significant differences in batting success between the two participants. They found that horizontal head movements were larger than horizontal eye rotations in both conditions of the study. Participant's gaze was directed near the ball throughout much of the pitch trajectory in the swinging condition until around the final 100 to 150 milliseconds, where gaze fell significantly behind the ball. This study showed that differences in head and eye movement strategies may influence batting strategy. However, it was not observed in this study if eye and head movements strategies influence hitting success. Due to the conflicting findings of previous studies looking at head movements, we will only focus on eye movement patterns in this study.

Smooth Pursuit Eye Movements

Smooth pursuit eye movements are one of the four basic types of eye movements. They are slower tracking movements where the eyes keep a moving stimulus on the fovea, and these movements are voluntary (Purves et al., 2001). Researchers have recorded smooth pursuit eye movements of baseball players in visual tracking tasks to analyze its relationship with DVA abilities. Bahill and LaRitz (1984) coordinated one of the first experiments to analyze the four basic eye movements of baseball players in a visual tracking task utilizing eye tracking equipment. There were three groups of participants in this study: university students, a varsity university baseball team, and one MLB player. The key finding of this study was the eye movement differences between the university students and the MLB player. The results showed that university students had significantly slower peak smooth pursuit velocities (50 degrees per second) than the MLB player (120 degrees per second). The MLB player was able to track the visual target with less than two degrees gaze error up to 5.5 feet before reaching home plate, while university students could only track the visual target up to 9 feet in front of home plate.

Palidis et al., (2017) assessed the DVA of expert baseball players further by conducting dynamic-object and static-object DVA. They wanted to see the relationship between the intricate smooth pursuit kinematics and saccadic eye movements with DVA. They tested the DVA in expert baseball players by tracking their eye movements as they visually followed Landolt-C rings moving between 50-70 degrees per second (randomized between trials). Immediately after the conclusion of the movement, participants had to select the location of the gap between four choices. They did not find a significant relationship between smooth pursuit latency and DVA. However, they found that absolute and minimum eye position error had a strong relationship with DVA. Smaller minimum and absolute eye position error led to lower DVA thresholds (more accurate gap responses). While components of smooth pursuit eye movements were related to faster visual stimulus tracking, the visual stimulus velocity was much slower than pitches seen by high level baseball batters.

Fooken et al., (2016) wanted to see how smooth pursuit eye movements influence visual search strategies and accuracy during an interceptive timing task. 42 varsity baseball players participated in their study. Participants viewed a black ball (visual stimulus) on a computer screen. At the start of the trial, the black ball would move across the screen and disappear at a certain point before a designated "hit zone"; participants had to accurately time and press the screen in the correct location of the ball's predicted flight path. The researchers manipulated the ball speed (24, 29, 34 degrees per second) and visibility duration (100, 200, or 300 ms) of the stimulus, while the launch angle remained constant across all trials (35 degrees). The visual stimuli's flight projections simulated a batted baseball. Before each experimental block, participants completed nine practice interception trials where the entire trajectory was visible. The practice trials allowed participants to understand and become familiar with the dynamics of the task. Fooken et al. (2016) found that the quality of participant's smooth pursuit eye movements was the most important indicator of their ability to accurately intercept the projected target trajectory. Some participants consistently intercepted the target early or late across all conditions, yet they found similar interception accuracy between the early and late interceptors. Though the late interceptors tracked the target for a longer duration while it was invisible, which increases spatio-temporal uncertainty, there were no significant differences in tracking error between early and late inceptors. However, they found that there were distinct tactics used by participants depending on if they intercepted the target early or late in the "hit zone". Early interceptors hit significantly closer to the memorized feedback position from previous trials with the same speed conditions than late interceptors. Late interceptors had superior smooth pursuit quality and smaller saccadic amplitudes than early interceptors. Their results indicated that early interceptors depended on a combination of eye movement accuracy and cognitive heuristics, while late interceptors solely relied on eye movement accuracy. A large proportion of the older, experienced varsity baseball players in this study used a late interception strategy, which could suggest it is a superior tactic. Although, smooth pursuit eye movements and interception strategies may differ in a high velocity hitting task and may not be feasible to utilize in an interceptive timing task with a moving stimulus as fast as a baseball.

Gaze Patterns

Gaze control is defined as the process of directing the gaze to objects or events within a scene in real time and in service of the ongoing perceptual, cognitive, and behavioral activity. Interceptive timing tasks are one of the three main categories of motor tasks that involve the control of gaze. In an interceptive timing task, an object moves towards the performer while the gaze and attention systems are used to read the object as it is delivered, track it as it approaches, and then control it as it is received (Vickers, 2007). An example of an interceptive timing task is hitting a baseball. Gaze-target synchronizations in a visual tracking task can be disrupted by larger anticipatory saccades (Maruta, Heaton, Kryskow, Maule, &Ghajar, 2012). These disruptions may indicate impaired predictive timing but remain to be seen in a baseball hitting task.

Quiet eye is defined as the final fixation or tracking gaze on a precise location that has a commencement before the start of a final, critical movement (Vickers, 2007). Quiet eye is a visual component seen in some interceptive timing tasks such as skeet shooting and ping pong. However, there has been relatively few studies that have looked at quiet eye in interceptive timing tasks where the target is moving at a high velocity, such as a baseball in an at-bat. Sun, Zhang, Vine, and Wilson (2016) conducted a study where participants wearing eye tracking equipment attempted to throw a ping pong ball at a circular moving target before it reached an end. To shorten quiet eye duration, Sun et al. (2016) had participants view of the visual stimulus occluded for a short amount of time (first 219 milliseconds on screen), a long period (first 324 milliseconds on screen), and no occlusion of the target. Participants quiet eye duration was shortest in the long occlusion condition, and longest in the non-occluded condition. Their results suggest that performance in the interceptive task decline when their quiet eye duration was shortest. However, this research used a visual stimulus that traveled slower than typical fastballs seen in baseball. It has not been determined if individuals can utilize quiet eye in an interceptive timing task with as quick of a duration as facing a 90mph fastball (about a 400-millisecond duration).

Anticipatory Eye Movements

There are many sports that involve interceptive timing tasks with high velocity objects. Baseball batters face pitches at velocities so fast, that anticipatory eye movements may be needed in order to succeed. Researchers have examined the anticipatory eye movements of hitters to see how this preparatory-movement phase visual search strategy influences task success. Shank and Haywood (1987) recorded the eye movements of expert and non-expert baseball players in the preparatory phase of batting. The participants watched a video of a pitcher going through his delivery of different pitch types from the wind-up and stretch pitching positions. While the reaction times between both groups was similar, there were significant differences in eye movements between experts and non-experts. First, the expert group had significantly higher correct responses on the type of pitch thrown. Second, the expert group fixated on the release point of the pitch during the final phase of the pitching motion. The non-expert group moved their eyes before the baseball was released; their eyes frequently moved from the release point to the pitcher's head (or alternate locations in-between) at the final phase of the pitch. The results of this study indicate that experts use more efficient anticipatory eye movements (by fixating on release points) to determine pitch type and trajectory. The efficient anticipatory eye movements of expert baseball players may allow them to process information more accurately and enables them to track the baseball with more precision than less experienced baseball players.

Zhang and Watanabe (2005) studied the saccadic eye movements of expert ball players (baseball, tennis, soccer, and basketball) and novice ball players. All participants performed a visual tracking task while their eye movements were recorded. The participants were instructed to focus on a fixation point in the middle of a screen, until a peripheral fixation point appeared on screen. Participants had to fixate on the peripheral stimulus as quickly as possible. There were four conditions in this study. A direction/time-unpredictable condition, a direction/time-predictable condition, a direction-predictable/time-unpredictable condition, and a direction unpredictable, time predictable condition. The results showed that the expert ball players only had significantly faster reaction times (shorter latencies) than novice ball players on direction-predictable conditions. The results suggest that these expert athletes may have a superior ability to pick up advanced visual cues during the movement-preparation phase, which allowed for faster response times in predictable direction task conditions. However, the expert athletes in this study came from a variety of different sports where different visual search strategies may be needed to succeed, so there may be differences between elite athletes from different sports.

The ability to track unpredictable moving targets is a skill needed in many fast ball sports such as baseball, tennis, cricket, etc. Therefore, superior anticipatory eye movements have been examined in elite athletes outside the sport of baseball (Abernathy & Zawi, 2007; Rowe, Horswill, Kronvall-Parkinson, Poulter, & Mckenna, 2009; Shim, Carlton, Chow, & Chae, 2005). Individuals with high level baseball experience have intercepted occluded moving stimuli more accurately than normal participants due to superior cognitive extrapolation in correctly predicting the future location of a moving target (Nakamoto, et al., 2015). Cognitive extrapolation is the brains ability to visualize a stimulus without it being present. Participants in the elite group of our study should have more accurate anticipatory eye movements compared to the sub-elite group, which will allow for more successful hits.

Kato and Fukuda (2002) recorded the eye movements of nine expert and nine novice baseball players as they viewed a baseball pitch. The participants were instructed to watch a video of a pitcher throwing ten pitches towards the participants as if they were batting (they were viewing the pitcher from the right-handed batter's box on a baseball field). The researchers wanted to find differences in visual search strategies between the two groups during the preparatory phase of batting, when the pitcher is going through the pitching motion. The results revealed that expert baseball player's fixation points were almost entirely on the shoulder-trunk region of the pitcher during their throwing motion, while the novice's fixations went up and down based on the movement of the pitcher during their throwing motion. Also, experts fixated on the pitcher's throwing arm, specifically at the elbow of the pitcher during their release point (final phase) of their throw, while the novices fixated on the shoulder region at the pitcher's release point. The findings of this study show that expert baseball players may use more effective visual search strategies by having a smaller fixation area, using more peripheral vision to evaluate the pitcher’s motion to gain a more accurate prediction of the ball trajectory. Kato and Fukuda utilized a visual tracking task that is similar to batting tasks in baseball games. While they only analyzed the eye movements of baseball players during the preparatory phase of batting, it gave a great insight into the anticipatory eye movements expert baseball players may use during batting tasks. Although, eye tracking movements need to be analyzed during all phases of a baseball at-bat to see how visual search strategies progress and influence success through the preparatory, initiation, and execution of a swing.

In a similar study, Takeuchi and Inomata (2009) progressed research further by having participants perform an interceptive timing task while recording their eye movements. There were two groups of participants, seven expert baseball players and seven novice baseball players. All participants watched a video of a pitcher throwing baseballs towards them in a simulated at-bat. Participants wearing eye tracking headsets were standing in the right-handed batter's box as each of them viewed ten pitches; the participants were holding a baseball bat with a button taped to the bat grip. If the participant's decided they would swing the bat at the pitch, then they would press the button on the bat with their right thumb. Participants had to decide whether the ball would be in the strike zone, and they had to correctly time the button (to indicate a successful swing decision time). They found that expert baseball players fixated on the throwing arm and release point of the pitcher significantly more than the novice group who primarily fixated on the pitcher's head and face. Additionally, the expert group shifted their eyes from the proximal part of the pitcher’s body (head, chest, trunk) in the early phases of the pitching motion to the arm and release point before the ball was thrown. Finally, expert baseball players were significantly more accurate in swing timing, and they made their swing decisions significantly earlier than the novice participants. The pitches thrown to both groups were not significantly different in velocity and accuracy, so both groups faced similar conditions. Takeuchi and Inomata's experiment provided further evidence of experts using visual cues from the pitcher's arm and release point to make anticipatory eye movements. Their research showed how these anticipatory visual search strategies used by experts could possibly influence their success in interceptive timing tasks. The next step is to have baseball players perform an interceptive timing task by swinging a bat against high velocity live pitches.

Müller, Lalović, Dempsey, Rosalie, & Harbaugh (2014) found that early visual information may influence the onset of the swing. The elite participant in this study (former MLB player) was able to initiate their weight transfer and bat downswing earlier than the less skilled (Australian Baseball League players) participants. Their findings suggest that the MLB player utilized more early visual cues from the pitcher, which influenced the onset of their swing mechanics. If viewing the mechanics of a pitcher in the preparatory phase has been observed in expert baseball players, can watching video presentations of elite pitchers be used as a training method? Morris-Binelli, Muller, & Fadde (2017) went the next step by examining whether viewing pitcher footage can improve visual anticipation skills and be used as training. The participants (N=105) in this study were all professional baseball players. Participants watched game-footage of elite pitchers, but their vision was occluded during the pitcher’s release point and at 80 ms or 200 ms after ball release. At the conclusion of the pitch, participants had to state the pitch type and location; participant's answers were correlated with their batting statistics. There was a positive correlation between slugging percentage and pitch type and location 80ms after ball release. The researchers found a significant negative correlation between pitch type anticipation 200ms after ball release and strikeouts. Finally, there was a significant correlation between pitch type anticipation after 200ms with on-base percentage and walk-to-strike ratio.

Their findings indicate that the early and middle sections of the ball flight path are needed to make an accurate swing decision and to generate enough force, that accurate prediction of later occluded pitches is related to less strikeouts, and that walks will increase and strikeout will decrease with accurate pitch anticipations during later occlusions. Overall, the study found that expert baseball players may be able to train visual anticipation skills by watching pitcher game-footage.

Vision Training

Finding the eye movement characteristics that help improve hitting success in baseball players can lead to development/training programs that will improve gaze pattern abilities in baseball players. Breaking down the many components of gaze pattern and finding the ones that influence hitting success is vital in creating a gaze pattern development or training program focused on improving hitting. Research has found visual acuity differences between baseball players and non-baseball players at the youth level (Boden, Rosengren, Martin, & Boden, 2009). Also, studies have shown that DVA develops with age in both males and females (Williams & Helfrich, 1977). Also, DVA may be influenced by gender (Kohmura, Yoshigi, Sakuraba, Aoki, & Totsuka, 2008). While there are already physical training programs aimed towards youth athletes (Szymanski, 2013), DVA development programs could be implemented at the youth level as well to create future batting success. Boden et al., (2009) found that youth baseball and softball players had better static stereo acuity than non-ball players. Their finding suggests that visual differences can be seen at an early playing age, and it may be due to the visual requirements needed to be successful in hitting a moving ball. DVA development programs could improve the eye movements in young athletes and help create higher levels of DVA abilities than kids that are not involved in these programs.

Baseball players utilize DVA while trying to have a successful at-bat during a game. However, there has been little research on eye tracking in baseball players that has been conducted that accurately simulates a real baseball at-bat. Recording the eye movement pattern differences found in expert baseball players can lead to the creation of training programs that enhance certain gaze pattern abilities at the high school level and beyond. Sports vision training programs have been implemented for some time; while these training programs have been shown to improve visual acuity, there has been insufficient evidence that it improves sport performance (Wood & Abernathy, 1997). Vision training programs have been utilized in order to enhance stereopsis and sensorimotor abilities in baseball/softball settings (Appelbaum, Lu, Khanna,& Detwiler, 2016; Clark, Graman, & Ellis, 2015) DVA training programs have been used at the college level with some success (Clark, Ellis, Bench, Khoury, and Graman, 2012; Deveau Ozer, & Seitz, 2014; Kohmura & Yoshigi, 2004). Clark et al. (2012) implemented standard vision training exercises in the University of Cincinnati baseball team training program for two years and found that the team improved their hitting statistics overall year over year. Many vision training exercises were used in the study, so it is difficult to determine which vision exercises worked versus which did not help. There have been previous experiments looking at the effects of sports vision training where athletes have found improvement in the vision exercises, yet they do not translate to visuomotor skills outside of the tasks (Abernathy & Wood, 2001). Researchers have been working to implement interceptive tasks that translate learning to the field, which makes the task more transferable for baseball players (Broadbent, Causer, Williams, & Ford, 2014). Finding the DVA differences between elite and sub-elite players can narrow down the aspects of vision that need to be trained to track and hit the baseball with more success.

Summary

Saccades are a major component of eye movement patterns, and it can be measured by latency, amplitude, duration, and peak velocity. Saccadic eye movement have been the most observed type of eye movement in high velocity interceptive timing tasks. Previous research on baseball players has not studied eye movement patterns of baseball batters during the baseball's trajectory in game-like hitting task. Due to the quick duration of an at-bat, efficient anticipatory eye movements are needed to have an accurate final fixation point while initiating the swing. Microsaccades are small involuntary eye movements where the brain is unconsciously fixated on a location, and it may explain how individuals can successfully hit a baseball, yet their voluntary fixation is not on the baseball (higher retinal error). Reverse saccadic eye movements occur when the direction of the saccades is traveling in the opposite direction of the visual stimuli. Previous studies have found reverse saccade usage to be negatively related to batting performance. Previous research has not looked at the influence of microsaccades in a baseball at-bat. Quiet eye is the final fixation on a specific location before the initiation of a responsive movement. The influence of quiet eye in a successful baseball at-bat facing high velocity pitches has not been studied in previous research due to the longer fixation time required for quiet eye, which may not be feasible in a baseball batting task. There have been conflicting results on the importance of vestibular-ocular movements in a baseball batting task, so the focus of this study will be strictly on eye movement patterns.

Chapter III. Methods

Previous research has analyzed the DVA and anticipatory skills of baseball players using sensorimotor tasks and interceptive timing tasks in lab settings. To our knowledge, there had been no previous studies that analyzed the eye movement patterns of baseball players during the trajectory of baseball in a baseball hitting task. Specifically, the eye movement patterns utilized from baseball release out of the pitcher's hand to the ball-to-bat contact.

Specific eye movement characteristics in a baseball hitting task are needed to be identified as an indicator for hitting success. Eye movements were recorded from a hitting task that replicated a batting task seen in a baseball game, in order to fully understand the sensorimotor actions required to successfully hit a baseball. An indoor baseball batting task with a live person pitching at consistent velocities was used for this study. The task employed in this study allowed us to observe eye movement patterns of elite and sub-elite baseball players that resembled those found in a real at-bat. Also, the procedures were conducted indoors, because it allowed us to keep consistent settings for the eye tracking glasses and motion capture equipment, as well as control for extraneous variables such as weather changes.

Subjects

All procedures in this study were approved by the East Carolina University Internal Review Board (IRB). All participants that volunteered signed a letter of consent after hearing an overview of the study. Participants were recruited from a varsity baseball team, club baseball team, and student population at a National Collegiate Athletic Association (NCAA) division one university. Also, participants were recruited from a National Junior College Athletic Association (NJCAA) division one varsity baseball team. All participants were required to have prior baseball playing experience since the age of 16, and they must have been currently over the age of 18. Participants were placed into groups based on skill level. The sub-elite baseball group were participants with previous baseball experience that did not play beyond the high school varsity level. The sub-elite participants needed to have baseball playing experience since the age of 16, so that they had some proficiency at hitting a baseball. Participants in the elite group had playing experience beyond the high school varsity level. The elite group participants' playing level ranged from collegiate club team to NCAA division one varsity team. There were 16 participants used in this study, eight in each group. However, only fourteen participants fully completed the hitting task due to equipment malfunction during two of the sub-elite participants batting session. Therefore, only the fourteen participants that completed the study were analyzed for the results. There were left-handed and right-handed batters used in this study.

Instruments

Participant's eye movements and fixation points were recorded using mobile eye tracking equipment. The eye tracker device was a SMI Eye Tracking Glasses 2 Wireless ETG16-1026 (SensoMotoric Instruments Inc., 2017), which uses an infrared (IR) corneal reflection eye tracker. It collects information at 120 Hz with a tablet wired to the device and has a fixation point accuracy within 0.5 degrees of the actual location (Figure 1). The Gaze & Motion Module provided real time streaming of 6D gaze vectors. The device is shaped like eyeglasses, and there are adjustable nose pieces that were used in case the participant was not comfortable wearing the device with the standard nose piece.

Figure 1

A pitcher was used to throw baseballs to all the participants. The pitcher threw two pitch types, a four-seam fastball and a curve ball. The velocities for each pitch type remained consistent across all participants, with natural minor fluctuations in velocity across the trials. The pitcher throwing from behind an "L-Frame" protective net, will be 40 feet away from the hitter. Only one pitcher was used to throw throughout the study in order to reduce variance in the hitting task between the participants. The researchers provided participants a 34-inch wooden baseball bat, but participants could use their own baseball bat if they preferred, since there are length and weight ranges in wooden bats allowed in at the MLB level. Participants could use gloves and/or pine tar if they used it in their normal batting routine. The velocity of every pitch during the hitting task was tracked using a radar gun across trials and participants.

Procedures

The testing procedures occurred in one day and required approximately one hour to complete for each participant. The data collection occurred at Next Level Training Center in Greenville, NC over the course of four days. The study was conducted at an indoor facility in a baseball hitting cage. A batting cage is a common baseball training setting; it is a large netted area used for hitting practice. Participants were scheduled based on their availability. Upon arrival, participants read through the informal consent and asked any questions they may have had. After they signed the informed consent, they answered a demographic questionnaire (Appendix A). The eye tracking equipment was calibrated for optimal accuracy using a three-point calibration display. The eye tracking equipment was checked for calibration after every five pitches during testing. Participants chose their bat, then put on the eye tracking equipment. The eye tracking glasses was connected to a Microsoft Surface tablet on the other side of the batting cage netting, so it was protected from potential damage due to foul balls. The eye tracking equipment was comfortably secured to the participant's head. After the initial calibration, the participants received five practice swings against fastballs thrown from the pitcher behind the screen. Participants were instructed to perform the hitting task as if they were in a real baseball game. Therefore, they were trying to hit pitches located in the strike zone, while not swinging at pitches outside of the strike zone. The practice swings allowed participants to get used to get swinging the baseball bat while wearing the eye tracking equipment and being attached to the recording device and allowed the hitters to get comfortable with the movement and velocity of the pitches thrown.

Once the participant took five practice swings, the participants faced pitches in three conditions from the pitcher, while wearing the eye tracking equipment. In the first condition, the pitcher threw five fastballs to the participants. The overall fastball velocity ranged from 41-48 mph, with an average velocity of 45.20 mph (SD = 1.38 mph). The average fastball velocity from 40 feet is equivalent to about 68 mph from 60.5 feet away. The overall curveball velocity ranged from 36-45 mph, with an average velocity of 39.98 mph (SD = 1.72 mph). The average curveball velocity from 40 feet is equivalent to about 60 mph from 60.5 feet away. Finally, the participants faced ten pitches in a third condition, where the pitcher randomly threw either a fastball or curveball. The randomization of pitches in the third condition more closely simulated the batting task conducted in baseball games than the first two conditions. Therefore, participants batting success may have been influenced by facing multiple pitch types with unpredictable frequency (Gray and Cañal-Bruland, 2018).

Data Processing

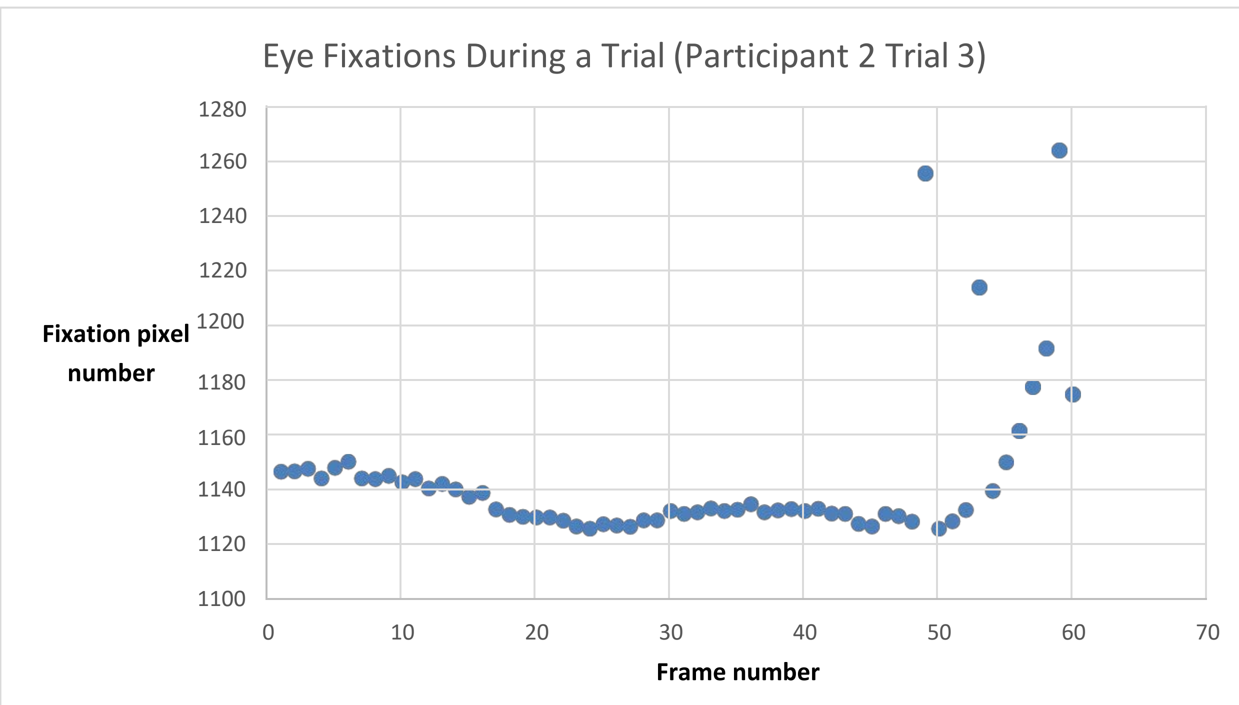
First, the demographic questionnaire recorded participant's age, height, weight, and whether they used prescription glasses or contacts for vision. Also, the questionnaire recorded the participant's highest playing level inside and outside of school, most recent season hitting results, primary position, and number of years played. Second, the participant's eye movements were recorded by the eye tracker glasses and was used to calculate fixation points captured by (IR) corneal reflection. Finally, the participant's hitting results were scored on a zero to three scale by the researchers: zero being a swing and miss, a one being a foul ball (hit outside of the field perimeters), two being weak to moderate contact in the field of play, and three was excellent contact. Also, participants were asked to score their own hitting results after each swing; this was done to provide more accuracy and consistency to the judgment of the hitting results. The participant's hitting score cards were recorded in a notebook during testing, and later transcribed to a Microsoft Excel Sheet in the Visual Motor Lab. The notebook was kept in the Visual Motor Lab at East Carolina University.

Next, the gaze patterns and errors of participant's eye movements were examined using the SMI BeGaze software through the area of interest (AoI) function. The eye tracking glasses provided a video recording of the user's field of vision. Elliptical-shaped AoIs were manually created over the baseball starting with the ball release from the pitcher's hand, through the ball flight path, and ending at ball-to-bat contact. Starting with the first pitch for each participant, AoI's were placed over each individual pitch during the hitting task. Two AoI types were created, AoI 1 for fastballs and AoI 2 for curveballs. All AoIs were created the same size and dimensions and were placed in the same locations during the hitting task. AoIs were created in all video recordings of the 16 participants. After the AoI's had been placed over all pitches across all participants, the raw data was exported from the BeGaze software. The AoI's raw data provided the vertical and horizontal fixation locations of participants in the video recording based on the 1280x960 video pixel dimensions (SensoMotoric Instruments Inc., 2017). Finally, the data from participant's eyes movements was analyzed across the three conditions. Also, these eye fixation locations were correlated with their trial hitting results to find relationships between eye movement patterns with hitting success.

Data Analysis

The eye movement recordings were averaged for the three hitting conditions for each participant and were statistically analyzed to observe any differences in eye movement patterns between the elite and sub-elite groups. The visual fixations from every trial were recorded from raw data exported from the BeGaze software (eye movements). Eye movements were measured by IR corneal reflection sensors in the glasses. These sensors can detect where the user was fixated in a three-dimensional space within 0.5 degrees accuracy (SensoMotoric Instruments Inc., 2017). The SMI software placed a marker on specific pixels of the video footage captured from the front of the glasses based on the IR sensors. For eye movements, scatterplots of each frame of the horizontal eye movements were used to indicate any large saccadic eye movements utilized during the task. The frame number where a saccadic eye movement started was recorded for all trials. The scatterplots displayed pixel location for the y-axis and time for the x-axis. (Figure 2). Horizontal eye movements were deemed efficient for capturing visual search strategies during the batting task due to exclusive use in a previous study (Fogt & Persson, 2017). Repeated measures ANOVA was conducted to observe hitting results and eye movements across the three conditions. The average time point of anticipatory saccadic eye movements during the baseball trajectory was analyzed using a series of univariate analysis of variance (ANOVA) between the elite and sub-elite groups in the three conditions. The difference in anticipatory saccadic eye movements occurrence between groups was assessed using a univariate analysis of variance (ANOVA). The hitting results of each group was scored on a scale between zero and three, which was assessed using ANOVA. The overall hitting results and anticipatory saccadic eye movements were assessed across the three conditions using MANOVA. The relationship within subjects was determined using a linear regression analysis. Pearson's correlation coefficient was used to analyze the relationship between anticipatory eye movement initiation time-points and the participants/observer's hitting result rating.

Figure 2



Chapter IV. Results

Hit Results

The hit quality results used in the data analysis were taken from the researchers' recording, this was done to prevent bias from the participant. There was a 74.1% agreement between participants and the researcher on their hit quality scores. The elite group had a higher average hit quality overall (M = 2.002; SD = .213) than the sub-elite group (M = 1.645; SD = .173), and there was a significant difference between the two groups and their hit results [*F* (1, 12) = 10.147; p = .008] (Figure 3). There was no significant difference in hit results by condition type between the elite and sub-elite groups [*F* (2,24) = .572, *p* = .572] (Figure 3). The elite group had a higher hit quality average in each of the three conditions.

Figure 3

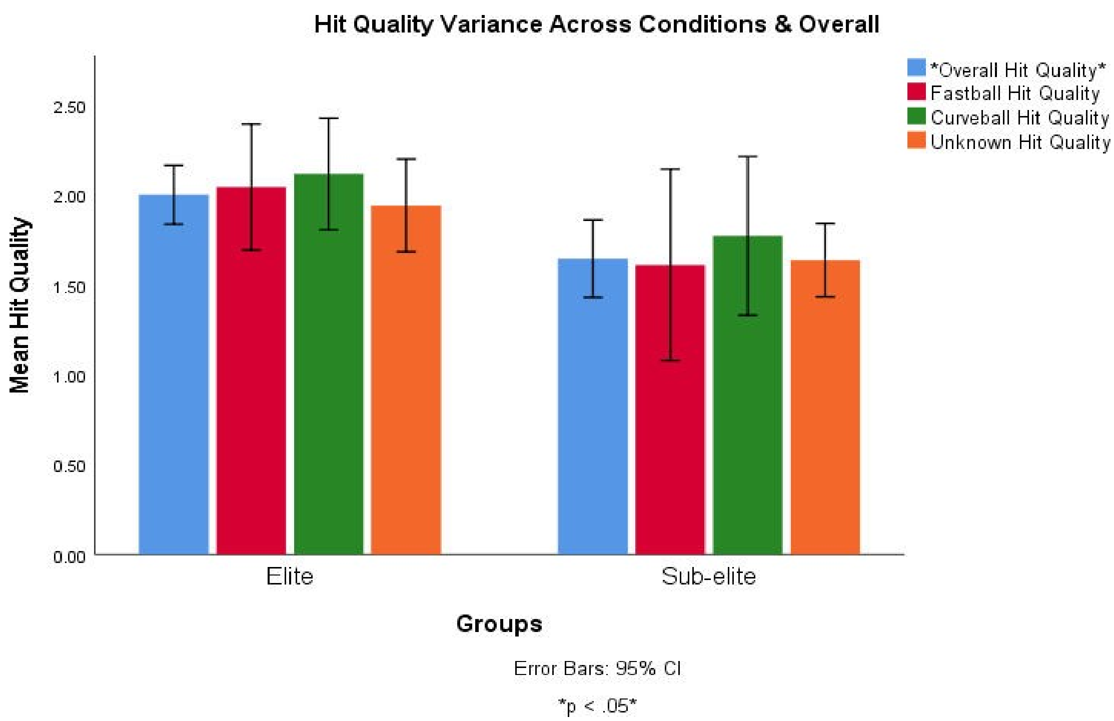


Table 1

Hitting Results by Condition

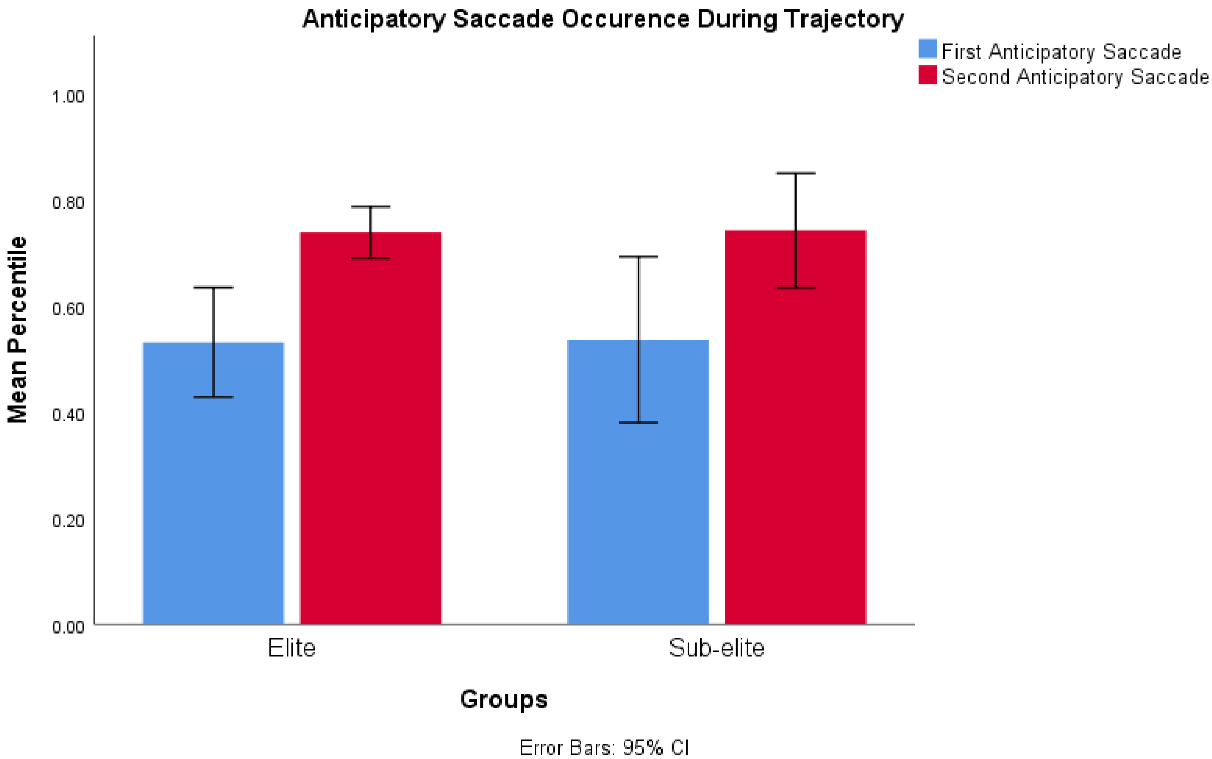
Descriptive Statistics	Groups	Mean	Std. Deviation
HIT RESULTS FASTBALL CONDITION	ELITE	2.044	.456
	SUB-ELITE	1.612	.429
HIT RESULTS CURVEBALL CONDITION	ELITE	2.118	.405
	SUB-ELITE	1.773	.355
HIT RESULTS UNKNOWN CONDITION	ELITE	1.942	.335
	SUB-ELITE	1.638	.165

Although the differences between the groups were not significant, the F values for the hit results between the groups across the three conditions indicates that there are noticeable differences between the groups. The total hit quality average and standard deviation were lowest in the third condition.

Eye Movement Patterns

We observed a visual search strategy trend among all participants. All participants would fixate around the ball during the first third of the trajectory, but then they would initiate a large horizontal saccadic eye movement ahead of the ball. We deemed the observed large horizontal saccade the "anticipatory saccade" or "eye shift". Repeated measures ANOVA indicated that the groups did not significantly differ in the time points of their first anticipatory saccade across the conditions [F (2,24) = .882, p = .427] and there was no significant interaction between condition and the anticipatory saccade initiation time-point [F (2,24) = 2.15, p = .138]. One-way ANOVA indicated there were no significant differences in the average time point of their first anticipatory saccadic eye movement [*F* (1,12) = .637, *p* = .440] between the elite and sub-elite groups (Figure 4). The elite group's first anticipatory saccadic eye movement initiation occurred earlier in the task on average compared to the sub-elite group.

Figure 4



The two groups were not significantly different between their average amount of horizontal anticipatory saccadic eye movements [*F* (1,12) = 1.37, *p* = .265] per trial. However, the elite group averaged more anticipatory saccades (M = 2.08) in each trial than the sub-elite group (M = 1.69). Pearson correlation results showed that there was a significant negative correlation between participant's first anticipatory saccade time point and their hit results [*r* (12) = -.547; *p* = .043] (Figure 5). The later the anticipatory saccade was initiated in the trial, the lower the participant's hit result.

Pearson's correlation revealed a significant positive correlation [*r*(12) = .651, p < .05] for the average time lapse between the first anticipatory saccadic eye movement and the last captured frame in the known conditions (conditions one and two) for all participants, but not the unknown conditions (Figure 6). There was no significant correlation between the average number anticipatory saccades [*r* (12) = .386, *p* = .173] with hitting results (Figure 7).

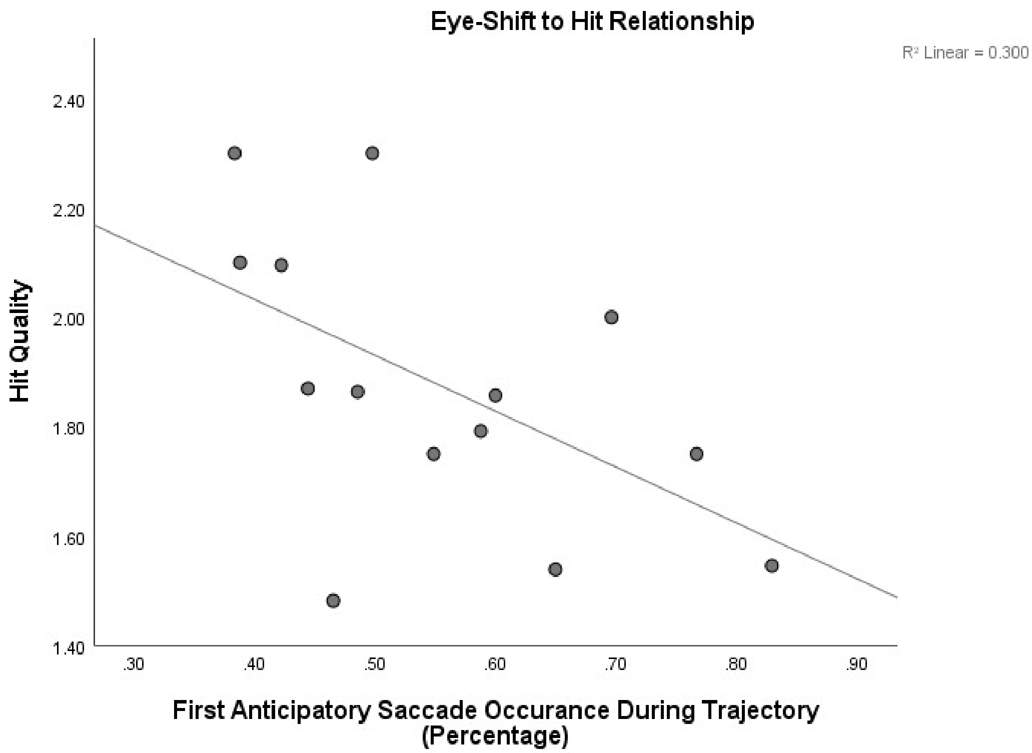
Table 2

Eye-Shift by Condition

Inferential Statistics		Fastball	Curveball	Unknown
EYE SHIFT FASTBALL CONDITION	Pearson Correlation		.651*	.298
	Sig. (2-tailed)		.012	.300
EYE SHIFT CURVEBALL CONDITION	Pearson Correlation	.651*		.479
	Sig. (2-tailed)	.012		.083
EYE SHIFT UNKNOWN CONDITION	Pearson Correlation	.298	.479	
	Sig. (2-tailed)	.300	.083	

*. p < 0.05 (2-tailed).

Figure 5


Eye-Shift to Hit Relationship
R² Linear = 0.300
2.40
2.20
2.00
1.80
1.60
1.40
Hit Quality
.30
.40
.50
.60
.70
.80
.90
First Anticipatory Saccade Occurance During Trajectory (Percentage)

p < .05

Figure 6

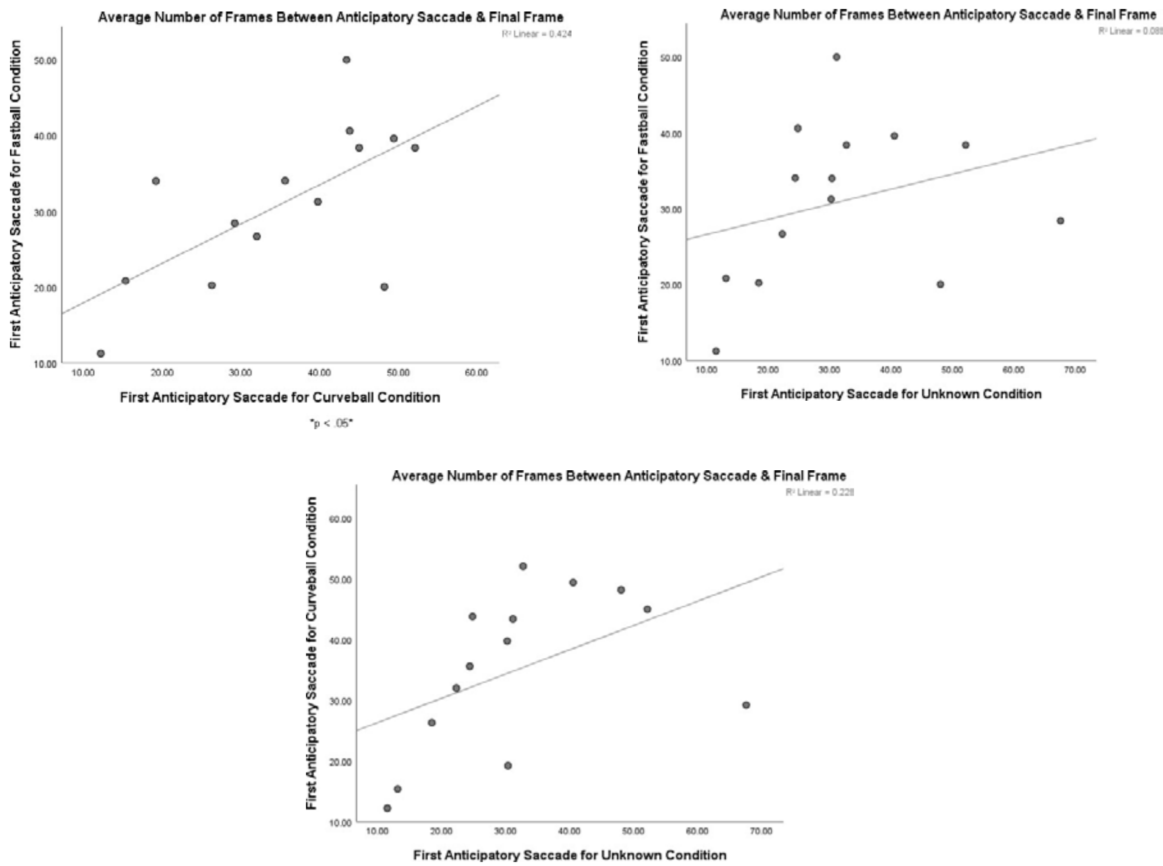
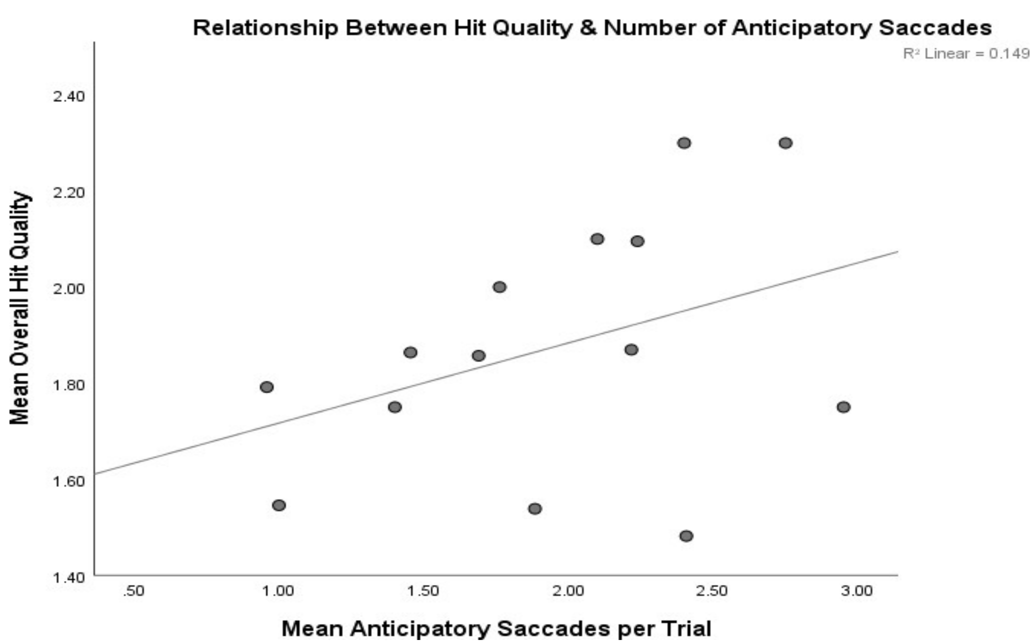


Figure 7



Chapter V. Discussion

Implications

The purpose of this study was to find distinct eye movement patterns relative to baseball players of varying skill level, high- and low-quality hits, and known versus unknown pitch conditions. The elite group had significantly better overall hit results compared to the sub-elite group, which confirmed one of the hypotheses. As far as visual search strategies, we observed that all participants fixated around the baseball during the first third of the trajectory. Then, participants made a large horizontal saccadic eye movement ahead of the ball's trajectory path, which we deemed the "anticipatory saccade" or "eye shift".

The elite group averaged just over two over of these anticipatory saccades per trial, which was higher than the sub-elite group. This finding refuted the hypothesis that the elite group would have less eye movements. The finding is surprising because it means the elite participant group was averaging one reverse saccadic eye shift per trial. Previous studies have found that reverse saccades negatively impacted hitting performance in baseball players (Palidis et al.,2017), but the elite participants in our study had significantly higher batting performance compared to the sub-elite group despite the reverse saccades. Previous research has been inconclusive on how baseball players of various skill levels differ in their eye movement patterns during the baseball's trajectory during batting tasks. The elite group initiated their first anticipatory saccadic eye movement faster than the sub-elite group, which confirmed the final hypothesis.

The elite group may have initiated their first anticipatory saccadic eye movement sooner because of the development of more efficient visual search strategies in their preparation phase

(Kato & Fukuda, 2002), superior extrapolation skills (Nakamoto, et al., 2015), and quicker pitch recognition due to additional experience (Shank & Haywood, 1987). Because the elite group initiated their anticipatory saccadic eye movements sooner than the sub-elite group, this may have given them more time to adjust their fixation point during the task. Therefore, the extra time allowed the elite participants to make reverse saccadic eye movements to refine their final eye fixations before contact, which contributed to the elite group having more overall eye movements than the sub-elite group. The data indicated that there were no significant differences in eye movement patterns between the groups, but the results still offered interesting insight.

One of the most interesting results from the study was the significant negative correlation between the time-point of the first anticipatory eye shift and hit quality [r (12) = -.547; p = .043]. The participants would focus near the baseball during the first half of the trajectory, then they would saccade to a location ahead of the ball before initiating their swing. The earlier the first anticipatory saccadic eye movement occurred, the more likely a high-quality hit would occur. The elite group averaged an earlier first eye shift compared to the sub-elite group, so the timing of their anticipatory saccade may have had some influence on their hitting success. There was also a significant correlation between the time points of the first saccadic eye movement in the known conditions. This finding suggests that participants may have utilized different search strategies when they knew what pitch type was coming compared to when they did not know the pitch type coming.

Understanding the eye movement behaviors of elite level baseball players can lead to improved scouting, development, and training for baseball players of all skill levels. Scouting is the area that can be impacted first, because scouts must recognize the eye tendencies of the best baseball players, and then search for that while scouting. One of the biggest takeaways from the study is the importance of the first anticipatory saccade. The earlier this movement can occur, the more likely a player is to have a good hit. This phenomenon could be an efficient way for scouts to assess baseball players eye movements, by measuring how fast they are making their anticipatory saccades during at-bats. Also, virtual reality technology could be employed to train baseball players on initiating their anticipatory saccadic eye movements sooner, which may improve batting performance.

Another way to expand research on eye movements in baseball batters is to compare these eye movement behaviors with elite athletes in other interceptive timing sports. There have been studies that have analyzed the eye movements of elite athletes in other sports, many of which include interceptive timing tasks (Ceyte, Lion, Caudron, Perrin, & Gauchard, 2016; Hayhoe, McKinney, Chajka, &Pelz, 2011; Maarseveen, Savelsbergh, & Oudejans, 2018; Martell & Vickers, 2004; Sarpeshkar, Abernethy, & Mann, 2017). While studying the eye movements of elite athletes from other sports may not fully pertain to the visual demands experienced by baseball players, there could be overlap in the findings. Eye movement patterns and visual search strategies observed in the current study may be comparable to other elite athletes performing their respective sport task. Correlations in eye movement between expert athletes in different sports would allow for DVA training and development that can apply to athletes in a multitude of sports. Alternatively, if no similarities are found between these elite athletes, it may suggest that DVA training and development needs to be specialized to the athlete based on the sport they play.

Limitations

A limitation of this study was the number of participants used. Due to technological issues, two sub-elite participant's data were not recorded for the study, so only results for 14 participants rather than 16 were analyzed for this project. Because the two participants not included in this study were both in the sub-elite group, it created imbalance between the two groups participant totals. Therefore, the current experiment was underpowered and made it more difficult to find significant differences between the groups with their eye movements. One reason we may not have found significant differences in eye movement patterns between baseball players despite significant difference in hit results, deals with motor skill versus perception. The participants in both groups may have had similar perception abilities while tracking the ball with their eyes, but there was a significant difference in their motor skill abilities that influenced their hitting results.

Another limitation to this the study was the hitting task utilized, which replicates a batting practice scenario commonly used by baseball players. Although, it does not replicate a hitting task that occurs in competition, the hitting task in this study occurred in a batting cage at an indoor hitting facility with lower pitch velocities and less pitch type variance. Baseball players hit a moving object that varies in direction and speed on each throw from 60.5 feet away with a wooden bat, which is difficult to reproduce indoors. Ideally, researchers should track the eye movements of baseball players in a hitting task that is as similar to a real game as possible, so that it can apply to game at-bats. Feedback from our participants revealed that the eye tracking glasses may have impacted their hitting approach and results. The eye tracking glasses are not a typical piece of equipment that baseball players wear, so it may have taken some participants longer to get acclimated to the equipment than other. Some participants commented how they had to initially move their head during the preparation phase in order to fixate on the ball. Therefore, the eye tracking glasses may have impacted some participants visual search strategies more than others based on how they track the ball with their eyes.

Another limitation to this study was that the procedures and demographics were not uniform for all participants and groups. Participants were supposed to receive five pitches in conditions one and two, then receive ten pitches in condition three. However, there were some participants that received more pitches than other participants to compensate for swings at poor throws from the pitcher. Also, the skill level within the elite groups varied a larger degree. The elite group had participants that played as high as the NCAA division one level or as low as NCAA division three level. Some participants in the elite group were currently playing at their highest level, while others in the elite group had not played at their highest level in several years.

A final limitation was that there were a couple alternative variables which may have influenced eye movement patterns and hitting success in our study. First, we did not record eye dominance among our participants, which may influence visual search strategies and batting success. Adams (1965) found that baseball players with unilateral eye dominance had a significantly higher on-base-percentage than cross-lateral eye dominant baseball players. Laby, Kirschen, Rosenbaum, & Mellman, (1998) studied whether eye dominance influenced batting performance in major and minor league baseball players. They did not find any significant relationship between eye dominance and batting performance among players at the major or minor league level. However, the unilateral dominant major league baseball players had a batting average 20 points higher on average than the cross-lateral dominant major league players in the study. These two studies warrant a further investigation into the influence of eye dominance on baseball batting performance and eye movement patterns. The second extraneous variable we did not analyze in this study was the eye movement patterns utilized before the pitch was thrown. Previous studies have shown that higher skilled baseball players fixate on more relevant cues before the pitch was thrown (Kato & Fukuda, 2002). The elite participants in our study may have been more efficient at recognizing the pitch type in the preparation phase during the pitcher's wind-up, which may have influenced their earlier anticipatory eye movements.

Future Research

Future research should track the eye movements of baseball players during competition to find any similarities or differences in eye movement patterns compared to the batting practice task in this study. The most valid method to study eye movements during baseball batting would be to measure it during a game. The eye movements of baseball players in future studies could be measured in competitive at-bats since eye tracking technology is becoming more sophisticated. There are new eye tracking devices that can measure and store eye movements using Bluetooth technology, which would allow users to wear the eye tracking devices without being wired up to a recording device. Eye tracking devices with Bluetooth technology would allow researchers to record eye movements of baseball players during competition from spectator locations since they would not have to be wired up to the eye trackers. It is important to see if the eye movement patterns result in this study replicate the eye movement patterns utilized in a game with much higher pitch velocities. The elite participants employed more reverse saccadic eye movements in their at-bats, which may have been due to the lower pitch velocities. If baseball batters faced high velocity pitches like that what is seen in competition, then there may not be enough time to utilize reverse saccadic eye movements. The elite participants in this study may have utilized eye movement patterns and visual search strategies that is unique to a baseball training scenario (batting practice in an indoor hitting cage). There may be unique eye movement patterns and visual search strategies that pertain to high velocity baseball batting tasks.

For participants and other measurements, future research should consider eye dominance to see if there is a relationship between visual search strategies and eye movement patterns to an individual's eye dominance (unilateral or cross-lateral). Future studies should recruit baseball teams of participants to analyze eye movements. Then, the skill level within groups will be closer to one another. There may have been too large of a motor skill difference between the elite and sub-elite groups in our studies, which may have impacted hitting results. Future studies should look at players from different competition levels that are closer to one another. For instance, researchers could look at eye movement pattern differences between AAA minor league players and rookie level minor league baseball players.

For measurements in future studies, the hit quality of participants could be measured by the exit velocity from the ball-to-bat contact. It would be a more objective measurement of hit quality versus the subjective scoring method used in this study. Finally, future research should examine the relationship between vestibular-ocular movements and batting performance. While there has been little research using baseball players, eye and head movements have been studied in elite athletes from other sports that utilize interceptive timing tasks, such as cricket. Researchers have found a relationship between head movements and visual search strategies during a batting task among elite cricket players (Mann, Spratford, & Abernethy, 2013), which suggests that head movements may play a role in batting performance. Therefore, vestibular-ocular movements should be further analyzed among baseball players during batting tasks.

For procedures in future studies, the ideal hitting task would be a "live batting practice" format, which can occur in a batting cage indoors. A live batting practice task consists of a pitcher on a mound 60.5 feet away pitching at game speed to a batter in a batting cage. Therefore, this type of hitting task would allow researchers to measure the eye movements of baseball players in a more game-like hitting task, with a lower risk of equipment damage. The batting task should include known and unknown pitch conditions to see if there are differences in gaze patterns when a baseball batter knows or does not know what type of pitch is coming. It would be best if the same pitcher is used for all participants, but it is more difficult when the pitcher is throwing with full effort due to fatigue and injury risk. The current study used one pitcher so that it would create more consistency for all the participants in this experiment. Therefore, the hitting task should be set up like innings in a game for the pitcher. The pitcher would throw a set amount to participants, then rest for about ten minutes and repeat. It is important to see if gaze patterns differ for a baseball batting task with pitch speed that replicates the velocity of pitches seen in competition, because any findings would be more pertinent to game-like batting.

Conclusion

The aims of this study were to distinguish eye movement patterns between baseball players of different skill levels during a baseball hitting task, to distinguish eye movement patterns relative to high- and low-quality hits and between known and unknown pitches. The current study did not find any significant differences in eye movement patterns between elite and sub-elite baseball players. Though, there were eye movement differences between the two groups that warrants further investigation. There was a positive correlation between eye movement patterns and the known conditions in this study, which could mean that visual search strategies are influenced by whether the individual has less knowledge of the visual stimuli movements before the trajectory. There was a significant correlation between eye movement and hit quality, which suggests that distinct eye movement behaviors can possibly play a role in batting success. Further research needs to be conducted on this topic, because it could have a major impact on how baseball batters are scouted, developed, and trained.

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Appendix A

Participant Demographics

Sub #:	Date:	Collector:
BASEBALL /SOFTBALL		
Height (m):		
Mass (kg):		
Age:		
Vision Prescription:		
Floor to ASIS:		
Floor to Lat Epicondyle of Knee:		
Mid-Thigh Height (tee height)		
When was your last season of competitive play?	Fall / Spring _________	
How many years did you play competitively?		
What was the highest level that you competed at for school?		
What was the highest level that you played at outside of school?		
What level were you playing at when you stopped playing?		
How many months/years did you play at your highest level?		
What was your primary position when you stopped playing?		
What was your batting average during your last competitive season?		

Appendix B

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board
4N-64 Brody Medical Sciences Building� Mail Stop 682
600 Moye Boulevard � Greenville, NC 27834
Office **252-744-2914** � Fax **252-744-2284** �
www.ecu.edu/ORIC/irb

Notification of Continuing Review Approval: Expedited

From: Biomedical IRB
To: Christopher Curran
CC:
Zachary Domire
Date: 1/9/2019
Re: CR00007481
UMCIRB 17-002568
Biomechanics of Baseball and Softball Swings in Training Settings

The continuing review of your expedited study was approved. Approval of the study and any consent form(s) is for the period of 1/8/2019 to 1/7/2020. This research study is eligible for review under expedited category #4,6,7. The Chairperson (or designee) deemed this study no more than minimal risk.

Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The Investigator must adhere to all reporting requirements for this study.

Approved consent documents with the IRB approval date stamped on the document should be used to consent participants (consent documents with the IRB approval date stamp are found under the Documents tab in the study workspace).

The approval includes the following items:

Document	Description
Swing_Drills_Protocol_Changes - Next Level.docx(0.05)	Study Protocol or Grant Application
SwingMoCap_F2017_Consent-NextLevel.pdf(0.08)	Consent Forms
SwingMoCap_F2017_Flyer 18-35.pdf(0.04)	Recruitment Documents/Scripts

The Chairperson (or designee) does not have a potential for conflict of interest on this study.