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An Exploration of Shifts in Visual Fixation Prior to the Execution of Baseball Batting: Evidence for Oculomotor Warm up, Attentional Processes or Pre-performance Routines?

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Abstract The visual performance of athletes should be considered high on the list of variables fundamental to elite sport performance. One particular aspect of visual performance that has gained dominance over the last 25 years is the quiet eye. Quiet eye is the final visual fixation of long, steady duration prior to the execution of a motor skill. However, as the concept of quiet eye has achieved dominance in the field of motor control, we know increasingly less about the visual behavior that precedes the onset of it. This is especially true for externally-paced interceptive tasks such as baseball hitting. The present study collected data on the visual scene using mobile eye trackers, as experienced by 58 professional baseball players during batting practice. The results suggest that athletes exhibit multiple dynamic shifts in visual fixation prior to the onset of quiet eye and the pitcher's action. Furthermore, cluster analysis revealed a significant positive relationship between the number of shifts in visual fixations and batting average, indicating that this visual skill may contribute to more efficient interception of the ball. The purpose of these dynamic shifts in visual fixation are proposed, alongside a call for further research to develop a deeper understanding of this pre-task visual behavior and its role in sport performance.

Keywords Baseball, Visual fixation, Eye tracking, Quiet Eye, Visual performance

1. Introduction

Elite level sport is a domain that attracts researchers from many different fields in the quest to discover the distinctive factors responsible for high performance [1]. To this end, physical variables, such as strength and agility and technical skills such as efficient biomechanics and neuropsychological skills have all been examined [2]. The examination of neuropsychological skills in athletes has specifically focused on the development of differences in visual behavior [3], decision making [4], perceptual expertise [5], memory [6], cortical activation [7], and pre-performance routines [8] as precursors of high performance. To isolate one of these variables as an example – pre-performance routines – research illustrates that expert athletes have a precise neural network that uses motor and visual information more efficiently than novices, the employment of which leads to enhanced performance [9]. It is the efficient processing of visual information that may be key to enhancing understanding of high levels of performance in sport. Indeed, 90% of input to the brain is visual [10], with 50% of the brain dedicated to visual processing [11]. Through the study of gaze behavior it is possible to ascertain the strategy athletes use to elicit information from the environment [12].

Among the most studied characteristics of gaze behavior are fixations and saccades. Fixations occur when an athlete maintains visual gaze on a single target, and saccades are conversely rapid, ballistic movements of the eyes that abruptly change the point of fixation [13], allowing the individual to scan the visual environment. Such gaze behavior can be measured by eye tracking equipment, and with the substantial development in this technology over the last few years, it is now relatively straightforward to collect

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data in situ by using mobile, wearable devices [14, 15]. Collecting gaze behavior data in situ is preferable to laboratory conditions as the data gathered is more naturalistic [16]. Indeed, wearable eye tracking equipment has been used to examine athletes' visual search behaviors such as where they look during the performance of their sport [17]. Such examples have revealed differences in visual gaze behavior based on skill level [18], the number of locations in which individuals look [19], their cognitive and information processing loads [20], and decision-making time and accuracy [21]. From an optometric perspective, when comparing the results of the visual performance of elite level athletes compared to non-athletes, differences emerge in relation to near-far focusing [22], depth perception [23], accommodation [24], static acuity [25], dynamic acuity [26] and peripheral vision [27]. The relative importance of the visual system in athletes has led some researchers to attempt to understand whether the ocular muscles need exercising and training in order to increase visual efficiency [28]. The results of these studies have historically been mixed with Abernethy and Wood [29] finding no evidence to suggest that visual training led to improvements in vision or motor performance, and Clark and colleagues [30] finding a significant increase in batting average from their baseballer recipients of their vision training regime. However, a review of digital training techniques associated with sports vision training by Appelbaum and Erickson [31] have suggested that there are "...many specific instances of tools and products that are available to train vision and cognition for the purpose of improving sporting proficiency" (p.21).

One area of visual behavior research heavily linked with sporting proficiency is the concept of "quiet eye" (QE). Vickers [32] defines QE as "the final fixation or tracking gaze that is located on a specific location or object in the task space within 3^{o} of visual angle (or less) for a minimum of 100ms." (p.1). Vickers [33] suggests QE refers to the brief moment when task relevancy is processed and motor plans are co-ordinated for an immediate task. Research has concluded that skill level is influenced by QE in open externally-paced skills such as baseball and cricket [34], and closed self-paced skills such as golf [35]. However, the relative effect of QE on the performance of these differently classified skills varies. For example, for in closed skills such as golf putting the late portion of QE supports performance [36], and in interceptive, closed skill tasks such as baseball hitting, an early QE is more beneficial [37]. Williams [38] suggests "the issues of identifying causal mechanisms [of QE] are compounded in tasks that involve interception of objects in flight and interactions with teammates and opponents" (p.2). He goes on to question the relevance of QE in any other tasks other than those involving aiming. In a more general criticism, QE has been challenged for being considered the main visual process occurring before an upcoming task, where, for example shifts in fields of view over time are important, particularly in externally-paced open skills such as handball [39]. In their experimental study Glöckner and colleagues [39] used handball players to investigate playmakers' choices and success. This research concluded that, in an external-skill based, team environment at least, that shifts of attention over time need to be acknowledged as predictors of motor skill success, and not only isolated fixations. Shifts in attention over time may be critical to success in externally-paced and interceptive sports for the purposes of extracting different, relevant information from multiple areas of display in the visual field. The importance of peripheral perception is also key (for an overview, see [40]), to motor execution success. Therefore, as Vickers [33] suggests, if fixated information is the only critical variable in successful motor execution, then there would be no role for the stimuli gathered from multiple areas of the visual field, including the periphery. Indeed, maintaining a steady fixation can aid pick up of peripheral vision. The term "visual pivot" is used to account for this, where a virtual fixation position that does not have significant value is used to elicit information from the periphery [41]. Support for the use of visual pivots in enhancing skill execution has been found in golf [41], boxing [42], and baseball [43].

Baseball is a sport requiring a high degree of visual processing, none more so than for the batters [30]. The speed of baseball pitches often exceeds the visual tracking capabilities of the batter [43], forcing the pick-up of advanced cues containing relevant information from the visual field prior to the release of the ball from the pitcher [43]. Advanced cues in "striking" sports are considered to be "game tactics, subjective probabilities, and an opponent's movement pattern" [44]. In baseball specifically, the pitch count and number of batters on base provide advance cues in baseball as to the likely next type of pitch and its location relative to the strike zone [45]. In addition, the kinematics of the pitcher's movement patterns help batters decide whether to swing or not swing at a pitch, with the goal of scoring a run or contributing to a run being scored [46].

Although it is understood that early visual information is part of an expert's specific visual search strategy that utilizes peripheral vision to predict the trajectory and speed of the pitched ball, little is understood regarding how to maximize this visual search for relevant information or indeed visual preparation for action. For example, is a visual warm up required or do batters simply enter the box and search for their preferred visual pivot before facing the pitcher? The purpose of this study therefore, was to determine if there were any differences in batters' oculomotor behavior *preceding* the onset of the visual search strategy prior to receiving a pitched ball. In addition, this study sought to understand whether there was a relationship between particular patterns of preparatory oculomotor behavior, offensive statistics such as on base percentage and batting average and length of professional baseball career in a sample of major and minor league baseball players.

2. Method

2.1. Participants

The sample consisted of 58 contracted professional baseball players from one Major League Baseball (MLB) team in the United States of America. The study was conducted during the team's pre-season training camp in 2013. Of the total sample, 13 were repeat major league competitors who were either contracted to the present team or were contracted to another baseball team during the previous season. The remaining 45 players were from the team's minor league system, attempting to make the major league roster for 2014. It is noteworthy to consider that the classification of minor and major leaguers is a fluid one; a player's assigned level of competition can change often within their career and even within the span of one season. Given this was training camp, none of the participants were guaranteed a position on the team's major league roster; their level of classification (major v. minor) would be determined at the end of training camp. The participants were all male and ranged in age from 24 to 48 years old (M = 32.00 years, SD = 3.54). See Tables 1 and 2 for descriptive statistics.

Table 1. Participant ethnicity and handedness

Ethnicity		Handedness	
Hispanic	22	Right-handed	41
White	20	Left-handed	11
Other (incl Black, Native Hawaiian)	16	Ambidextrous	6

Table 2. MLB versus minor league batting statistics

	MLB	Minor League
At-bats	3185 (SD = 1761)	1987 (SD = 1051)
Overall batting average	0.27 (SD = 0.02)	0.24 (SD = 0.45)
On base %	0.34 (SD = 0.03)	0.31 (SD = 0.16)
On base slugging %	0.77 (SD = 0.07)	0.72 (SD = 0.50)

2.2. Apparatus and Stimuli

Applied Sciences Laboratory (ASL) mobile eye technology ("eye tracking device") was used to gather the visual eye tracking data. The participants wore the eye tracking device during live batting practice on the playing field. During the live batting practice, players swung at pitches. All pitches were thrown from a regulation distance of 60 feet 6 inches (18.44 meters) by the one pitcher. The eye tracker was used in the present study to collect data on the visual scene as experienced by the athletes. This data was coded and analyzed for subsequent analysis.

2.3. Procedure

The present study was approved by East Carolina University's Institutional Review Board. After providing written informed consent to participate in this study, the individuals were met on a one-to-one basis by the researcher in an office adjacent to the practice field. The researcher explained to the players that they were participating in an assessment of the visual-motor behavior and visual responses that batters elicit when attempting to hit a pitch. The participants were informed that the data gathered would be shared with the team coaching staff, and anonymously with the academic community. Each participant was then fitted with the eye tracker, which was calibrated to ensure the data collected was accurate. The players then walked out to the field and took 10 swings in response to pitches. The same pitcher was used for all batters. The batters were tested in a randomized order which meant that some participants experienced a delay of several minutes between being fitted with the eye tracker and entering the batter's box. After their batting practice session, participants left the field and returned to the office where the eye tracking apparatus was removed and the participants were debriefed by the researcher. All testing took place over two days. The visual tracking and video data obtained from the eye tracking device included the equipment fitting phase, to batting practice, and to the return of the equipment to the researcher. The video data gathered from each participant was downloaded into mp4 format. The video data provided environmental context to this study and served as an ecologic frame for the eye tracking data.

2.4. Data Analysis

Videos files of the visual behavior data captured by the eye tracking devices were first edited to ensure the footage for analysis included the batting practice period only from the time the individual stepped into the batter's box, to the time they left. For the purposes of coding, the visual behaviors exhibited by the individuals were coded from entry into the batter's box to their first strike at the ball. The visual behaviors exhibited by the athletes prior to hitting involved a pattern of shifts in visual focus prior to the ball being pitched. 'S*hifts in visual focus*' in this context were defined as multiple shifts of visual fixations from the home plate (near) to the pitcher (far) and vice versa, in preparing to hit the ball during active batting practice. The frequency of these shifts in fixations were coded and recorded for each participant separately by three researchers for inter-rater reliability (IRR). An IRR analysis was performed to assess the degree that coders consistently identified the frequency of shifts in fixations. The marginal distributions of frequency of shifts in fixations did not indicate prevalence or bias problems, suggesting that Cohen's [47] kappa was an appropriate index of IRR [48]. Kappa was computed for each coder pair then averaged to provide a single index of IRR [49]. The resulting kappa indicated almost perfect agreement, κ = 0.81 [50], consistent with previously published IRR estimates obtained from coding similar constructs in previous studies. The frequency of shifts in visual fixation data was added to the individuals' previous season statistics that included on base percentage, batting average and time in professional baseball to explore relationships between variables. Although the assumption of normality was met, the initial exploratory data analysis revealed a bimodal distribution of data (See Figs 1 and 2) which warranted further investigation. To this end, to generate visual profiles of professional baseball players, a cluster analysis was conducted.

Hierarchical and nonhierarchical cluster analyses were conducted using a two-step process to improve stability in the cluster solution [51]. Using standardized scores, the observed variables (on base percentage, batting average, and time in professional baseball) were entered into the cluster analysis. The first stage involved a hierarchical cluster analysis using Ward's linkage method with squared Euclidian distance measure to determine the number of clusters in the data. Ward's method is an agglomerative clustering method based on sum-of-squares criterion and produces groups that minimize within-group dispersion [51]. The second stage involved a k means (nonhierarchical) cluster analysis by specifying the most appropriate cluster solution from stage 1. After identifying the visual profiles, we performed separate univariate ANOVAs using the dependent visual control variables (frequency of shifts in visual fixation, near focus, far focus, first focus) to explore differences between clusters. Lastly, eta squared (η^2) were used to determine effect sizes.

3. Results

Descriptive statistics and frequency distributions of shifts in visual fixation and on-base percentage (OBP) and batting average (BA) are presented below in table 3 and figs 1, 2 and 3.

A hierarchical cluster analysis was conducted using Ward's method with a squared Euclidean distance measure on the standardized visual control variables. The agglomeration schedule coefficient and the dendrogram classified two clusters as possible solutions. This two-cluster solution was deemed acceptable according to empirical considerations which included the examination of the dendogram, satisfactory group sizes, maximizing differences, parsimony, and how interpretable the cluster solution was given the research question of interest. Next, a k means cluster analysis was conducted on the standardized visual control variables for the two-cluster solution. The nonhierarchical solution provided support for the hierarchical analysis. To provide a descriptive indication of the strength of our cluster solution, we conducted a MANOVA on the effect of the cluster membership. The MANOVA revealed a significant multivariate effect on cluster membership, Wilks' Lambda = .729, $F(8, 35)$ =141.789, $p < .01$, η^2=.729, thus indicating reasonable support for our cluster solution (see Fig 4).

Descriptive statistics (on base percentage, batting average, near focus, far focus, first focus, visual calibration) for the two clusters were evaluated by separate one-way analysis of variance. Cluster 2 demonstrated a significantly higher on base percentage, $F(1, 46) = 94.09$, $p < .001$, η^2=.681, and a significantly higher batting average, $F(1, 46) = 31.13$, $p < .001$, η^2=.414, than cluster 1 (See Table 3). A significant difference was also found for total number of shifts in visual fixation between clusters, $F(1, 46) = 4.92$, $p < .05$, η^2=.429. Cluster 2 demonstrated significantly more shifts in visual fixation ($M = 8.633$; $SD = 2.84$) than cluster 1 ($M = 5.68$; $SD = 5.27$). No cluster differences were found for the remaining variables.

Table 3. Descriptive statistics for batting average and on base percentage

	Clusters	Mean	Std. Deviation
Batting Average	1	.2484	.01524
	2	.2622	.02605
On Base Percentage	1	.2786	.01049
	2	.3076	.01651

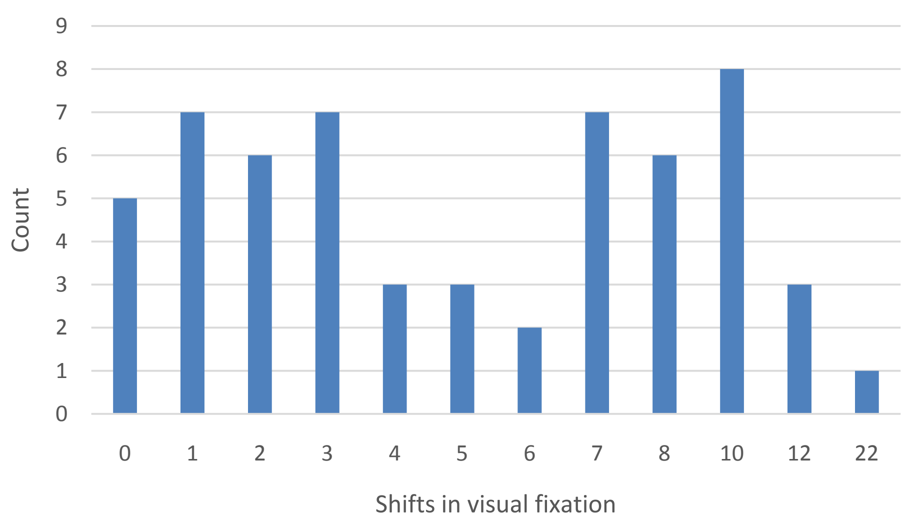

Figure 1. Frequency distribution of shifts in visual fixation

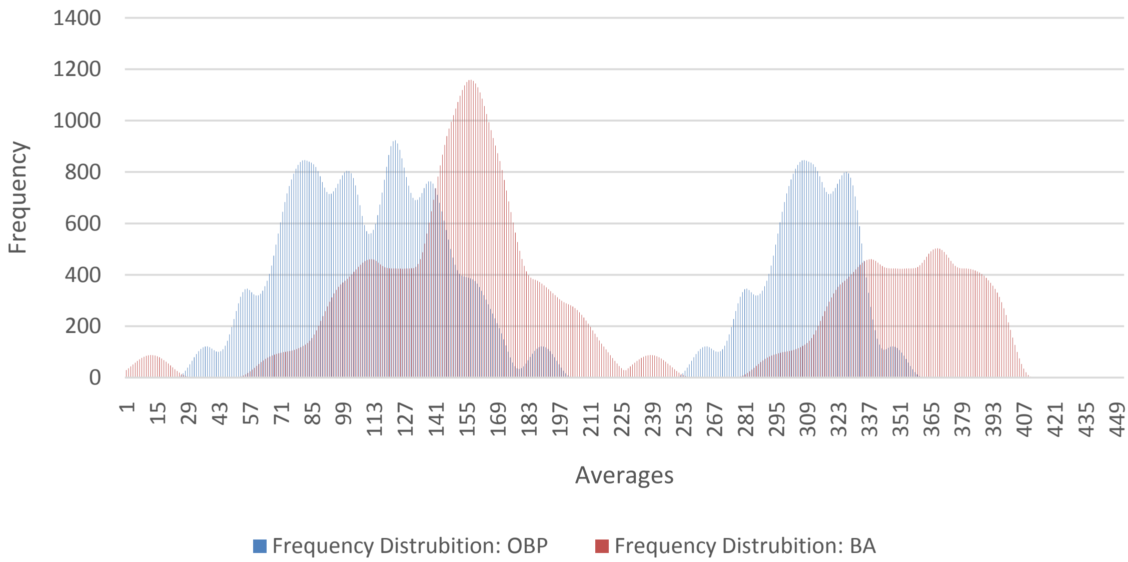

Figure 2. Frequency distribution for on-base percentage (OBP) and batting average (BA)

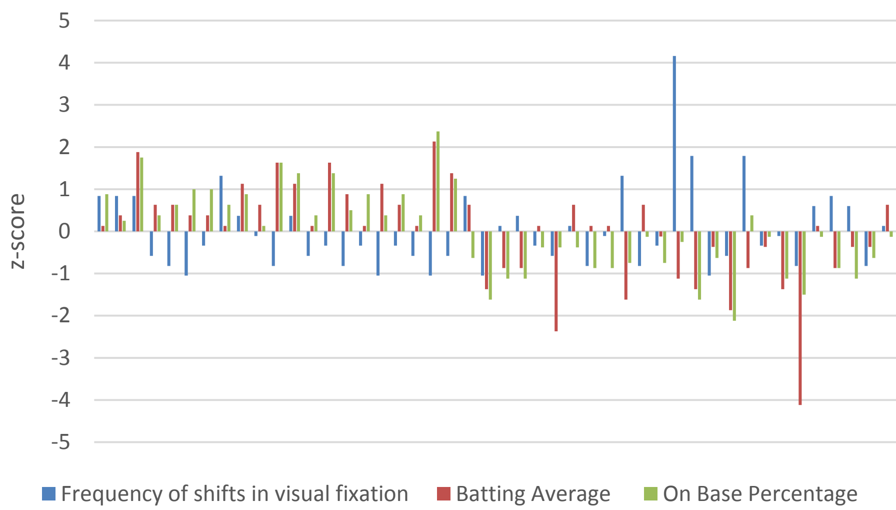

Figure 3. Z-score of frequency of shifts in visual fixation, batting average, and on base percentage for each cluster

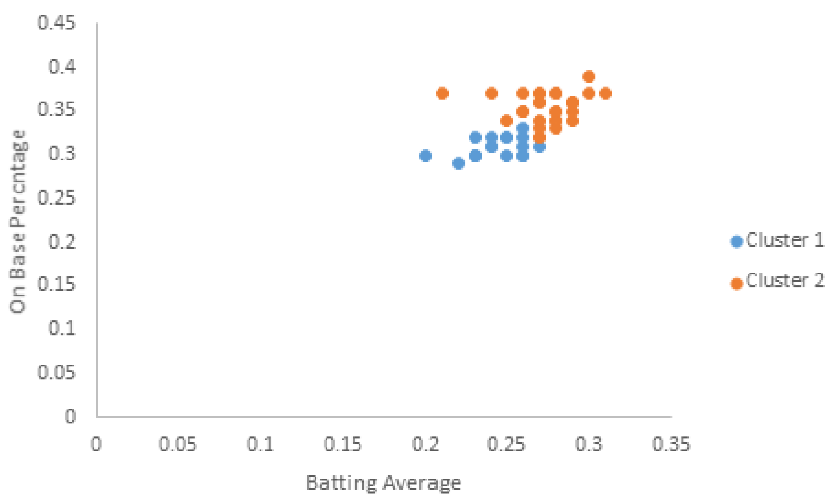

Figure 4. Hierarchical cluster analysis

In addition, a 2 (Cluster) x 9 (time) univariate analyses of variance with repeated measures on the last factor was conducted on each individual pitch shift in visual fixation. Analysis for individual pitch calibration indicated a non-significant main effect, $F(8, 112) = 1.73$, $p = .098$, $\eta^2=.110$, and a non-significant finding for Cluster x Time interaction, $F(8, 112) = .538$, $p = .825$, $\eta^2=.037$. However, a significant main effect for Cluster was found, $F(8, 112) = 9.0$, $p < .05$, $\eta^2=.391$. The results demonstrate a consistent pattern of shifts in visual fixation across time and a significant difference between clusters. Cluster 2 (better performers) tended to shift fixation on almost all pitches (95%) whereas Cluster 1 shifted fixation on approximately 60% of pitches.

4. Discussion & Conclusions

The results of the present study indicate the existence of preparatory oculomotor behavior in batters prior to the onset of the visual search strategy before receiving a pitched ball. This behavior amounted to frequent shifts in visual fixation from the home plate (near) to the pitcher (far) and back again. Furthermore, players with superior offensive batting statistics were observed engaging in more frequent shifts in fixation from near to far and vice versa, prior to the onset of their skill-specific visual search strategy, indicating perhaps a greater perceptual-cognitive advantage. These findings lend further support to notion that visual gaze behavior differs according to skill level [18] – specifically in the case of the present study, discrete differences in skill level.

The clustering effect between offensive performance and frequency of shifts in visual fixation leads to further considerations of these findings. The first consideration of the results extends to the purpose of the shift of visual fixations. If the frequency of this visual behavior has a positive relationship with sport performance, there are a number of options to consider that may account for this phenomenon. Those options involve the optimization of the visual system for impending action. Therefore, the shifts in visual fixation may be indicative of dynamic eye exercises for the purposes of perhaps warming up the extraocular muscles, in a similar way to skeletal muscle [52, 53], which serves to improve visual concentration, dynamic and static visual acuity. Secondly, it is suggested that the technique of shifting visual fixations may relate to the generation of spatial attention, where the athlete considers their position in the environment relative to the position of the stimulus for the purposes of enhancing neuronal responsiveness [54]. Alternatively, shifting visual fixations from the home plate to the pitcher and back again, as observed in the current study, allows the fixation on each of these regions while allowing the extraction of information from neighboring regions in the periphery [55, 56]. Therefore, this visual behavior may indicative of a practiced technique to orientate the batter within the baseball field, and generate an awareness of the regions in the periphery that may be useful for information extraction (e.g., the bases, location of fielders etc...). A further perspective worthy of exploration is the possibility that the visual behavior may be representative of a pre-performance routine executed before the initiation of a motor skill [57]. Although previous research has determined that pre-performance routines increase sport performance in basketball, pistol shooting and archery [58-60], these studies all involved *visuomotor* behavior rehearsal. In the current study, the technique of shifting visual fixations may have been indicative of visual-only rehearsal techniques such as imagery, with an emphasis on cognitive components of a pre-performance routine [61]. These interdisciplinary approaches each provide different perspectives to examine in greater depth in future research to determine the nature and contribution of these preparatory eye movements in baseball batting.

There were a number of limitations associated with the present study. Firstly, there was no measurement of visual behavior beyond the preparatory phase. Therefore, there was no measure of the quiet eye [62] as the final fixation directed to a single location prior to the execution of the interceptive task. Further analysis combining the entirety of the individuals' visual behavior in the preparatory phase and oculomotor behavior during batting, combined with individual batting accuracy would have provided more holistic data from which to draw conclusions. It is suggested that future research considers this data collection strategy. Secondly, the present study was conducted during batting *practice* and thus, there were no distractions present as in real game competition. The batting practice context lacked many potential peripheral visual stimuli: runners on base, stadium backgrounds, defensive player movements, and even base coach’s signals. These participants had no distractions before each pitch, yet shifted their fixations in a standard pattern, near-to-far, and far-to-near. additionally, in order to determine the nature of these patterns of fixation, showing the batters the eye tracking data collected and asking them whether their visual behavior was a conscious strategy would have enhanced our understanding of these occurrences. It is suggested that future research employs this strategy.

The practical implications of this present study point out that different skill sets require different visual motor behaviors in order to perform efficiently at an athletic task. But the frequency of baseball players’ shifts in visual fixation during batting practice sustains an argument as to whether visual behavior prior before the onset of visual pivots and QE have significance in the context of enhanced skill execution. For training protocols and performance assessments, these different visual behaviors should be fully understood and introduced to the competitor. As a visual behavior, shifting visual fixations prior to the onset of an interceptive task is a learnable behavior that any athlete can utilize in training and competition.

Further research into this phenomenon is needed particularly to discern the different effects types of sport venues (closed v. open skills) have on the task performance. Furthermore, it would be beneficial to be able to distinguish whether the pre-performance dynamic shifts in visual fixation are a training-only behavior. Since it is neither possible to measure dynamic shifts in visual fixation in an ecologic context nor in a critical context during real completion, we cannot assume this behavior is consistent from training to game.

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