Journal of Expertise
2021. Vol. 4(1)

ISSN 2573-2773

To Tee, Or Not to Tee: Exploring the Relationship Between Representative Practice and Performance in Highly Skilled Baseball Hitters

Matthew McCue and Nick Wattie
Faculty of Health Sciences, Ontario Tech University, Canada

Correspondence, Matthew McCue: matthew.mccue@ontariotechu.net

Abstract

Expert batters utilize context-specific information and gaze behavior to aid decision-making and performance. However, typical practice and warm-up (PWU) activities often lack relevant context-specific information and visual cues that exist in competition. This study examined if drills varying in competition representativeness have an acute influence on decision-making and gaze behavior. Twenty-eight advanced baseball batters participated in one of four traditional warm-up drills and subsequently predicted pitch information in an 18-pitch simulation while wearing a mobile eye tracker. While no statistically significant warm-up condition effects were noted, descriptive results suggest that warm-up condition may have negatively affected gaze behavior. Results support research of high-performance batters as players of advanced skill were more proficient at pitch recognition (t (26) = 2.41, p = .02) and demonstrated more optimal visual search strategies (F (1, 27) = 13.06, p = .003, η_p^2 = .50). Additionally, handedness and pitch type predicted success in decision-making. Namely, left-handed batters made more total correct predictions than right-handed batters (F (2, 26) = 5.03, p = .01, η_p^2 = .28) and all batters were significantly better at predicting fastballs than other pitch types (F (2, 26) = 30.90, p < .001, η_p^2 = .70). Results suggest that athletes' frequent exposure to the unrepresentative PWU activities may have subsequently resulted in a skill in recalibration. To gain a better understanding of perceptual-cognitive skill development, future research should explore a potential skill in recalibration and the influence that unrepresentative PWU may have on gaze behavior and decision-making in more novice athletes.

Keywords

Perceptual-cognitive skill, representative learning design, sport expertise, perception-action coupling, recalibration, gaze behavior, decision-making

Introduction

The recent sign-stealing scandal in Major League Baseball (MLB) echoes a sentiment that has rung true for many years: professional batters need all the help they can get. Opposing pitchers are throwing harder than ever (although, Sullivan, 2019 suggests that velocity has plateaued) and are using high-speed cameras to refine their pitch designs. With batting being such a time-constrained task and strikeouts on the rise, it is unsurprising that some professional teams sought an edge and turned to modern technology to provide their batters with hints about the upcoming pitch.[1]

Regardless of sign stealing, MLB players demonstrate astounding perceptual-motor skill on a consistent basis. Indeed, research suggests that elite athletes, particularly in interceptive sports, rely on efficient visual search strategies (e.g., location and duration of gaze fixations) during competition (Mann, Williams, Ward, & Janelle, 2007; Marteniuk, 1976). Specifically, expert hitters fixate their gaze on more task relevant areas (i.e., throwing arm and release point) and take less time to first fixate on these areas, in comparison to novices (Kato & Fukuda, 2002; Takeuchi & Inomata, 2009). With a more efficient gaze behavior, experts are then able to process task relevant cues quickly and use them to inform anticipation and decision-making processes expeditiously (Gray, 2009c). Although there are limitations and technical considerations in eye-tracking research (see, Andersson et al., 2010; Kredel et al., 2017, for an excellent model and systematic review) these findings are robust across expertise literature (Bard & Fleury, 1976; Hubbard & Seng, 1954). This research typically focuses on the prevalence, description, and training of expert gaze behavior in high performance sport, yet the acute impact of the practice and warm-up (PWU) environment on perceptual-cognitive skills remains relatively unexplored.

The perceptual-cognitive skills indispensable to striking a baseball at the professional level are a key element of perception-action coupling, the pairing of movements (i.e., actions) with the necessary contextual and perceptual information provided by an opponent and/or game situation. Namely, professional batters weigh probabilistic information (i.e., the likelihood of a particular pitch being thrown in a circumstantial game situation), with visual information (i.e., kinematics of the pitcher, the velocity, trajectory, and spin of an approaching pitch), to inform what movement (i.e., when and where a swing should take place) is required to be successful (Gray, 2009b, 2009c). This attuned link between perception and action is likely the product of countless repetitions in competition, practice, and warm-up environments. Indeed, the performance difference in perceptual-cognitive skill between experts and non-experts is amplified when experts are able to execute movements associated with perceptual-cognitive skill (e.g., anticipation and decision-making; Farrow & Abernethy, 2003). However, many traditional PWU environments in baseball do not preserve or reinforce the link between perception and action. For example, a quick exploration of an MLB hitting facility will undoubtedly uncover at least one practice tee. The use of a mounted ball on a stationary tee is a classic drill used by baseball players, and it is emblematic of unrepresentative practice activities that do not reinforce perception-action coupling.

Literature suggests PWU that highly resembles competition, representative learning environments (RLEs), positively influence skill acquisition and performance (Pinder, Davids, et al., 2011; Pinder et al., 2009). The representativeness of a particular PWU environment consists of two key features: functionality and action fidelity (Krause et al., 2017). The functionality of RLEs is the extent to which an athlete may use informational cues in practice that are also present during competition to direct decisions and movements (Pinder, Renshaw, et al., 2011). Action fidelity refers to an RLE's ability to preserve an athlete's movement pattern that is typically seen in competition (Araújo et al., 2007). However, a large proportion of traditional PWU baseball drills are slightly or entirely unrepresentative of competition. For example, a ball machine is often used in baseball PWU to simulate a pitcher. While this drill can replicate the velocity and trajectory of real pitches, it rates quite low in functionality as the batter is not provided with key informational cues such as the wind-up and variable release point of the opponent (Abernethy & Russell, 1984). Importantly, learning environments low in representativeness can have a significant impact on performance and learning. Pinder et al. (2009) demonstrated that ball machines also rate low in action fidelity as they significantly influence the spatiotemporal kinematics of novice cricketers. Further, the inclusion of low functionality/action fidelity drills in PWU environments have led to undesirable swing kinematics in tennis (Reid et al., 2010) and negatively affected the extrinsic timing of volleyball players (Davids et al., 2001). However, the majority of research projects in this area has a strong biomechanical focus (i.e., the movement portion of the perception-action link) and do not explore the potential acute disruption that unrepresentative practice has on perceptual-cognitive skill.

Brand and de Oliveira (2017) used recalibration to demonstrate the necessity of warm-up for perceptual-cognitive skill performance. It was suggested that while warm-up has traditionally been viewed as a time to prepare relevant muscles and tendons, it is also essential for the recalibration of the precise relationship between complex movements and dynamic visual and/or contextual information. Athletes rely on perception-action links to perform but are frequently exposed to disturbances to these links (see Rieser et al., 1995; Scott & Gray, 2010, for mechanisms to disrupt the perception-action link and induce recalibration), and must use warm-up to recalibrate. As such, the necessity of recalibration may present as a strong argument for those who condemn MLB's traditional warm-up routine. Before each game, many players participate in coach-thrown batting practice on the field. Despite research that suggests the efficacy of pitching in a variable manner during batting practice (Hall et al., 1994), this task typically consists of a coach repetitively delivering one type of pitch from a shortened distance, at a reduced velocity, to the same location. Relative to what a batter may encounter in a competition — such as multiple pitch types, high velocities, and varied locations of pitches — this drill is unrepresentative and thus may not adequately recalibrate their sensorimotor network system.

Coach-thrown batting practice, among other PWU tasks low in functionality or action fidelity, are ubiquitous in baseball. While the negative biomechanical consequences of low representative PWU is well-researched, the recent discourse about MLBs warm-up routine (Hall, 2019; Waldstein, 2012) and unplumbed relationship between representative PWU and perceptual-cognitive skill performance suggests that empirical research is needed. Thus, the purpose of this study is to explore the *acute* effect of common warm-up batting drills on the gaze behavior and decision-making of advanced baseball players. Specifically, the aim of this study was to explore the acute influence of three typical baseball warm-up conditions—stationary tee drill, pitching machine batting practice, and coach-thrown batting practice—on players' decision-making and gaze behavior. We hypothesize the following:

(i) Drills that are more de-coupled (i.e., stationary tee drill) will likely elicit a greater negative influence on gaze behavior (i.e., sub-optimal visual search strategies), and decision-making (i.e., pitch type and location prediction) than drills that are less de-coupled (i.e., coach-thrown batting practice).

(ii) Players of higher skill level should demonstrate more optimal visual search strategies and decision-making than players of lesser skill level, regardless of handedness, occlusion time, and pitch type.

Materials and Methods

Participants

Twenty-eight male baseball players participated in this study after written informed consent was obtained (this research was approved by the Ontario Tech Research Ethics Board). A priori sample size estimation suggested that with a power level of .80, and a mean effect size (f = .70) derived from previous skill x condition designs on baseball hitters (Castaneda & Gray, 2007; Gray, 2017), the current sample size would be sufficient to detect statistically significant skill x warm-up condition interaction effects. Pre-trial questionnaires, inquiring about skill level, handedness, and age were completed prior to experimental trials. Results were used to balance and ensure a high degree of similarity between experimental groups. Fourteen tier one, or higher-skilled, athletes were identified by their receipt of an athletic scholarship from a National College Athletic Association, National Junior College Athletic Association, or National Association of Intercollegiate Athletics institution, or through participation in a semiprofessional/amateur league. Fourteen tier two, or lesser-skilled athletes, participated at a collegiate level (i.e., Ontario University Athletics and Ontario Colleges Athletic Association), but never played in the tier one institutions/leagues. However, all athletes in this sample can be classified as advanced (Baker et al., 2015) as these leagues are reflective of national level or high-level intercollegiate competition. Tier one participants' mean age was 21.8 years (*SE* = .73) and tier two participants' mean age was 21.1 years (*SE* = .58). Additionally, 18 participants were right-handed hitters, and 10 participants were left-handed hitters. Although this was an unequal value, this represents competitive distribution, as left-handed hitters are less common in professional baseball.

Procedure

Warm-up protocol. A between-subjects experimental design was implemented to measure how four warm-up conditions (with seven participants per condition) of differing task representativeness acutely influenced the gaze behavior and performance of advanced baseball players. Participants were quasi-randomly assigned to experimental groups; first tier one athletes were randomly assigned to experimental groups, then tier two athletes were randomly assigned to experimental groups, to ensure approximately equal distribution of skill levels across experimental groups. A similar quasi-random approach was used to assign participants to experimental groups based on their handedness (in terms of their batting stance). The control group was instructed to warm-up completing twenty "dry" swings with no ball involved. The stationary tee group hit a ball off a standard Tanner Tee™, which is a device that holds a ball in a stationary position and allows athletes to swing repetitively at the same location. The pitching machine group swung at a ball delivered from a pitching machine that stood 60 feet and 6 inches from the batter (the regulation distance of a mound to home plate: Official Baseball Rules, 2018), at a velocity of 85 miles per hour (identified in the pre-study questionnaire as the average velocity the athletes see at practice). Finally, the coach-thrown batting practice group struck a moving ball delivered from 45 feet away by a coach certified by the Ontario Baseball Association. All participants completed twenty swings in their respective group.

Simulation. Once warm-up was complete, participants were fitted with a SensoMotoric Instruments Mobile Eye Tracker[2], which was configured through a three-point calibration utilizing an image of the simulation pitcher and participants in a batting position. Each batter then stood five feet away from a projection screen, on which a pitcher was projected and scaled to appear to be 60 feet and 6 inches away (regulation distance). The batter observed eighteen consecutive pitches with a break of 15 seconds between each pitch. Participants were instructed to swing or not swing at simulated pitches with the same intent seen in a game to preserve perception-action coupling and an immersive atmosphere that more completely replicates real-game movements and decisions. Three different pitch types were used in the trial: fastball, curveball and changeup.

The ball flight was temporally occluded with a black screen at 333 milliseconds, 200 milliseconds, and 100 milliseconds after ball release from the pitcher's hand. These occlusion times stem from Adair's findings centered on the physics of baseball and decision-making (Adair, 1995). Immediately after the completion of a swing, the athletes were asked to verbally indicate the pitch type (fastball, curveball, and changeup) and final pitch location. A scaled strike zone segmented into four quadrants was displayed directly below the projection screen for visual reference (see Figure 1). This think aloud protocol and verbal indication of final pitch location has previously been used for cricket batters (McRobert, Ward, Eccles, & Williams, 2011). The athlete was asked to complete their swing (or their take if they chose not to swing) before indicating pitch type.

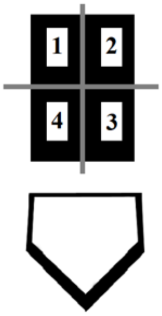

Figure 1. Scaled strike zone that batters used to determine pitch location and ball or strike.

Variables

The main independent variable in this study was the warm-up condition that the participants completed (i.e., stationary tee, pitching machine batting practice, coach-thrown batting practice, and control). Two secondary independent variables, playing level (tier one or two) and handedness (right or left), were also included in analyses to determine their potential effect on gaze behavior and decision-making.

Decision-making. Three nominal dependent variables were monitored to capture decision-making: pitch type (i.e., fastball, curveball, and change-up), quadrant location (i.e., pitch location as it crosses the plate; see Figure 1) and ball or strike. The sum of correct predictions were calculated as well and reported as total correct predictions.

Gaze Behavior. Fixation behavior was the main gaze behavior variable that was monitored. The criteria for a fixation was the gaze remaining stationary within 1.5° of visual angle for a duration greater than 120 ms (Takeuchi & Inomata, 2009). Fixation behavior assessment (location and duration) for all 18 pitches in the trial began 500 ms before release of the ball and continued until the ball was released.

One nominal and three ratio dependent variables were utilized to assess gaze behavior: location of fixations pre-release of the pitch (legs, trunk/torso, head/neck, elbow/release point, and unclassified), duration of fixations in each location, Time to Release Point Fixation (TtRPFix) – the amount of time (in ms) before the batter initiates a fixation on the release point, and Final fixation duration (Fix*f)* – the duration (in ms) of the last fixation the batter makes before the ball is released. The timing of TtRPFix indicated if any of the warm-up conditions acutely affected the batter's ability to efficiently and accurately locate the release point of the ball. Additionally, Fix*f* and TtRPFix provided insight about the quickness of identifying task relevant areas (i.e., a low TtRPFix suggests the participant located the release point promptly) and their visual focus before the ball was released.

Analyses

Decision-making. A three-way factorial ANOVA was employed to analyze total correct predictions (pitch type + quadrant + ball/strike) with warm-up condition, handedness, and playing level as the between-participants variables, and occlusion segment (late, mid, and early) as the within-participant variable. A two-way factorial ANOVA was performed that assessed pitch type predictions (correct or incorrect) with warm-up condition and handedness as the between-participants variables, and occlusion segment and pitch type (fastball, curveball, change-up) as the within-participant variables.

Gaze Behavior. Following a similar structure to total correct predictions, the total number of release point fixations and Fix*f* were analyzed separately through the use of three-way factorial

ANOVAs with warm-up condition, handedness, and playing level as the between-participants variables and occlusion segment as the within-participants variable.

The TtRPFix outcome variable presents challenges for analyses as it resulted in a number of missing values for each pitch where a fixation on the release point did not occur. Furthermore, an imbalance in the number of TtRPFixs between individuals was likely as it would be improbable to expect a homogenous number of fixations on the release point. For these reasons, a linear mixed model, which does not perform listwise deletion and is thus robust to missing data points (Krueger & Tian, 2004) was performed. Warm-up condition, handedness, and playing level were entered into the model as effects with TtRPFix as the dependent variable.

Decision-making X Gaze Behavior. A chi-square test of independence was performed to explore the relationship of between final fixation point (release point or other) and pitch type prediction (correct or incorrect). Additionally, a binomial logistic regression was used to determine if Fixf could predict pitch type prediction performance (dichotomous – correct or incorrect).

Analyses were performed using G*Power (Faul, et al., 2007) and SPSS version 25, and statistical significance was defined as $p < .05$, at the 95 % Confidence Interval (CI).

Results

Decision-making

No significant effects of warm-up condition on total correct predictions, *F* (3, 13) = .13, $p = .94$, $\eta_p^2 = .03$, or pitch type predictions, *F* (3, 13) = .52, $p = .68$, $\eta_p^2 = .11$, were observed. Analysis of total correct predictions revealed a main effect of occlusion, *F* (2, 26) = 5.43, $p = .01$, $\eta_p^2 = .30$, with athletes predicting more correct pitches in the early occlusion segment (*M* = 8.68), compared to 7.35 and 7.14 in the middle and late occlusions, respectively. Additionally, tier 1 athletes made significantly more total correct predictions (*M* = 24.86, *SD* = 4.45) than tier 2 athletes (*M* = 21.5, *SD* = 2.71), *t* (26) = 2.41, $p = .02$. Analyses of correct pitch type predictions demonstrated a main effect of pitch type, *F* (2, 26) = 30.90, $p < .001$, $\eta_p^2 = .70$, as well as significant interactions of pitch type x handedness, *F* (2, 26) = 5.02, $p = .01$, $\eta_p^2 = .28$ (see Figure 2), and pitch type x occlusion, *F* (4, 52) = 19.18, $p < .001$, $\eta_p^2 = .60$. Accordingly, left-handed batters performed better, and batters were significantly better at predicting fastballs than other pitches, which was amplified by earlier occlusion times.

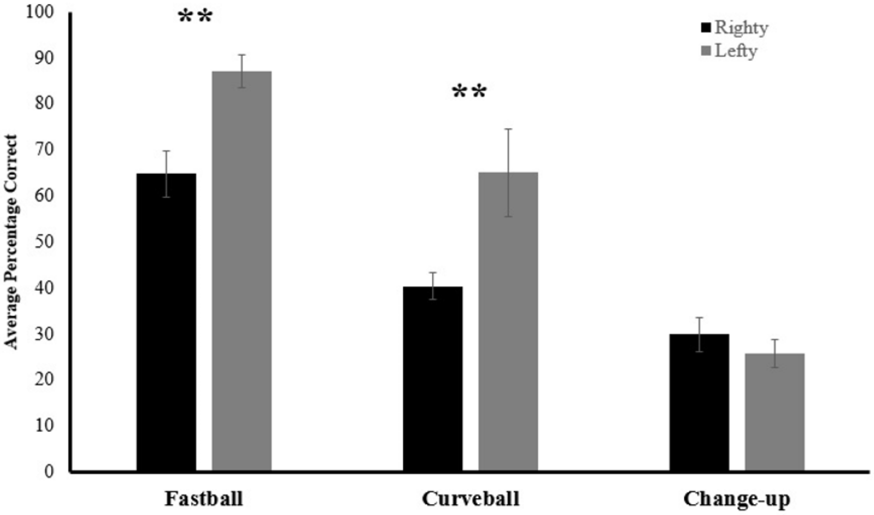

Figure 2. Percentage of correct predictions for each pitch type - handedness. Right-handed batters = black bars; left-handed batters = gray bars. Error bars represent standard error. ** represents significant difference at $p < .01$.

Gaze Behavior

Percent viewing time. Batters in the control condition spent significantly less time fixating on the release point, and more time fixating on task irrelevant arears (i.e., overshot release point and other), than players from the other three warm-up conditions (see Table 1). Tier 1 players spent significantly more time fixating on the release point (*M* = 48.05%, *SD* ± 9.04) than tier 2 players (*M* = 36.44%, *SD* ± 10.34). Although three different pitches were used in the simulation, batters did not display significantly different visual search behaviors to a specific pitch type.

Table 1. Percent viewing time of visual display (pitcher and baseball field).

	Legs	Trunk/Torso	Neck/Head	Release Point	Ball Flight	Overshot RP	Other	Back Elbow
	M (*SD*)							
Playing level								
Tier 1	**3.31** (3.73)	**32.14** (17.05)	**11.44** (13.08)	**48.05** (9.04)	**2.00** (3.30)	**.89** (1.86)	**.67** (2.51)	**1.49** (2.17)
Tier 2	**13.13** (16.22)	**20.82** (13.19)	**19.68** (18.27)	**36.44** (10.34)	**4.83** (6.66)	**2.28** (6.11)	**1.11** (1.93)	**1.69** (2.59)
Warm-up condition								
Control	**12.91** (11.22)	**18.9** (11.14)	**20.62** (13.71)	**31.1** (10.22)	**7.47** (6.87)	**5.41** (8.04)	**2.24** (3.48)	**1.31** (2.39)
Stationary tee	**4.59** (5.64)	**31.63** (17.72)	**13.4** (15.33)	**44.25** (12.13)	**2.76** (3.36)	**0.44** (1.18)	**0.84** (2.22)	**2.04** (2.88)
Pitching machine	**8.19** (14.22)	**26.99** (16.38)	**13.33** (19.39)	**45.5** (9.29)	**2.95** (6.22)	**0.47** (1.25)	**0** (0)	**2.53** (2.5)
Coach-thrown BP	**7.19** (17.62)	**28.38** (18.62)	**14.88** (18.21)	**48.11** (5.04)	**0.46** (1.21)	**0** (0)	**0.47** (1.25)	**0.47** (1.25)

Note. Overshot RP = Too far right of the release point but not considered other; Coach-thrown BP = Batting practice thrown by a coach; *M* = mean; *SD* = standard deviation. Numbers presented as percentages of total viewing time.

Release point. The three-way factorial ANOVA with number of release point fixations as the dependent variable revealed main effects of occlusion, F (2, 26) = 3.87, p = .03, η_p^2 = .23, and playing level F (1, 27) = 13.06, p = .003, η_p^2 = .50 (see Figure 3). Accordingly, tier 1 players averaged more fixations on the release point than tier 2 players did, and all players averaged more fixations on the release point in the mid and early occlusion segments compared to the late occlusion segment. No main effects of warmup condition or handedness were observed. Assessment of fixation locations suggest that tier 1 players also spent significantly more time fixating on the release point (*M* = 44.21%, *SD* = 2.48) than tier 2 players (*M* = 28.24%, *SD* = 2.59).

The linear mixed model ANOVA yielded similar results as a main effect of playing level on TtRPFix was observed (*df* = 1; *F* = 16.81, *p* = .001) with players from tier 1 averaging a quicker TtRPFix than tier 2 players (see Figure 3). Additionally, no main effects of warmup condition or handedness were observed. However, a significant interaction of playing level x warmup condition was noted, *(df* = 3; *F* = 3.93, *p* = .03).

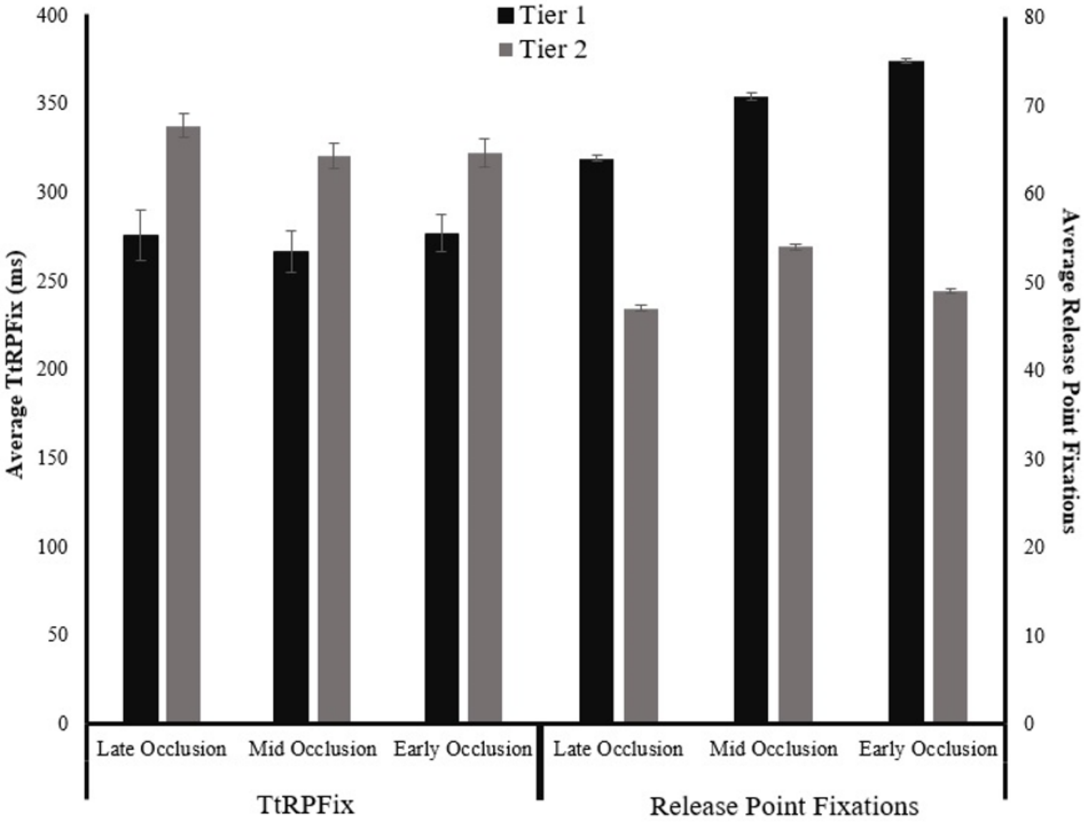

Figure 3. Visual search strategies as they pertain to release point for tier 1 and tier 2 players. TtRPFix = Time to Release Fixation, Late Occlusion = 333 ms occlusion, Mid = 200 ms occlusion, Early = 100 ms occlusion. TtRPFix bars to be scaled to the left primary y axis; release point fixation bars to be scaled to right secondary y axis. Error bars represent standard error.

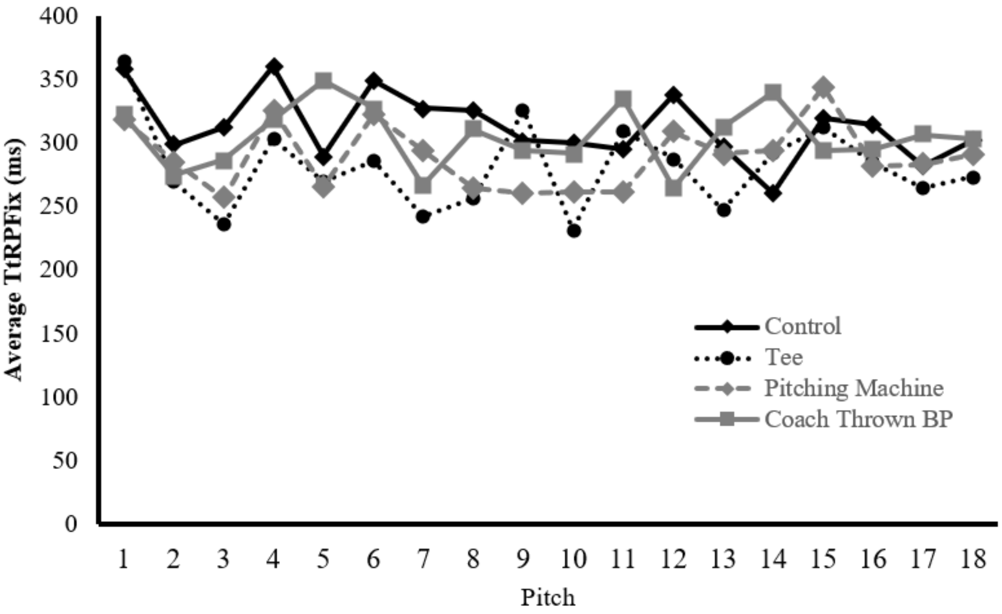

Figure 4. Average Time to Release Point Fixation (TtRPFix) of the four warmup conditions for each pitch. Pitches graphically represented in order they were presented to athletes.

Fixf. The duration of the final fixation before release of the ball appeared to be negatively correlated to TtRPFix, $r = -.82$, $p < .001$. Consequently, the three-way factorial ANOVA with Fix*f* as a dependent variable indicated a main effect of playing level, $F\ (1, 13) = 9.36$, $p = .01$, $\eta_p^2 = .42$, and significant interactions of playing level x warmup condition $F\ (3 ,13) = 3.83$, $p = .04$, $\eta_p^2 = .47$, and handedness x warmup condition $F\ (3, 13) = 3.79$, $p = .04$, $\eta_p^2 = .47$. No main effects of occlusion, warmup condition, and handedness were noted.

Decision-making x Gaze Behavior

The relation between final fixation location (release point or other) and correct pitch type identification was significant, $\chi^2\ (1) = 78.67$, $p <.001$, $\phi_c = .395$. Batters made significantly more correct pitch type predictions when they were able to fixate on release point directly before the release of the ball. The logistic regression model used to ascertain the effect of Fix*f* on the ability to predict pitch type was statistically significant ($\chi^2\ (1) = 6.85$, $p = .04$, OR .99, 95% CI: [.995, 1.00]), although only marginally and with negligible effect size.

Discussion

The goal of the current study was to explore the acute influence that unrepresentative batting drills may have on the decision-making and gaze behavior of advanced baseball players. An additional focus was to explore how variables such as playing experience, handedness, occlusion time, and pitch type may affect these results. Consistent with previous research on skilled baseball hitters (Kato & Fukuda, 2002; Takeuchi & Inomata, 2009), the location and duration of the batters' fixations appeared to be a significant indicator for decision-making success, and a predictor of playing experience. However, the lack of an unambiguous warm-up condition effect did not align with our hypotheses, or literature that suggests de-coupled practice may negatively affect batting performance (Pinder et al., 2009; Reid et al., 2010). Nevertheless, descriptive as well as inferential results of the current study may have implications for skill acquisition as it relates to de-coupled practice and warm-up activities, and therefore important directions for future research. Specifically, there were indications that warm-up condition may *and* may not have affected the batters.

While no clear main effect of warm-up condition was observed, potentially meaningful interactions between warm-up condition and playing level were noted with respect to gaze behavior. Players who warmed-up in the coach-thrown and pitching machine batting practice groups fixated their gaze on the release point more quickly on average in the first pitch of the simulation than those in the tee and control groups (see Figure 4). Namely, participants who completed the tasks more representative of competition were able to fixate on the release point in the first pitch of the trial quicker than those who completed the less representative tasks. This observation was not statistically significant, but it does support our first hypothesis, which predicted an acute de-coupled warm-up effect. Similarly, when assessing the percent viewing time for all warm-up conditions (Table 1), the control condition spent less time fixating on task relevant areas, such as release point and trunk/torso, and more time fixating on task irrelevant areas. This suggests that their visual search strategy of the pitcher's delivery may have been disrupted by the most de-coupled of the warm-up conditions. It is also possible that the results for warm-up condition were not conclusive because of the surprising proficiency of the tier 1 players in the tee condition; three of these players ranked in the top four of the entire sample in speed of release point fixation onset and duration (i.e., TtRPFix and Fix*f*). As such, it is possible that the visual search abilities of the players in this group were a confounding factor. It should be noted, however, that these three players progressively improved their gaze behavior (with respect to the release point) across trials (similar to the rest of the sample), which aligns with our first hypothesis.

The decision-making results may also suggest an acute influence of a de-coupled warm-up effect. A main effect of occlusion time was noted as athletes made more total correct predictions in the last segment of pitches (early occlusion) in comparison to the first segment (late occlusion). Although the trial was getting progressively harder (i.e., less ball flight information) the participants were able to make better use of contextual information to inform decision-making. These findings are similar to McPherson (1993) which suggested that batters analyze an opponents' characteristics and use this contextual information to predict subsequent pitches. However, another possibility is that the athletes' poorer decision-making in the earlier trials may have been the result of an acute negative influence of de-coupled warm-up. Ultimately, our inability to parse these two possibilities/results may have been due to the study design (see limitations section below).

It must also be considered that these drills simply did not acutely influence the decision-making or gaze behavior of advanced baseball players. This may be due to a lack of an influence of warm-up modality on decision-making and gaze behavior. Another possible interpretation of these results is that this sample's advanced skill may have allowed the participants to overcome the acute influence inflicted by de-coupled warm-up. Although previous research suggests that de-coupled practice disrupts the extrinsic timing and spatiotemporal kinematics of skilled performers (Davids et al., 2001; Pinder et al., 2009), perhaps any disruptive influence on gaze behavior and decision-making are mitigated by skill and the nature of the task. This postulation may be supported by the observation that skilled athletes can recalibrate quickly after a disruption (see Scott & Gray, 2010). Additionally, for the near entirety of these athletes' careers they have likely been warming-up utilizing these common tasks prior to batting in competition. We speculate that to some degree, these athletes may have developed a skill in recalibration. Future research with samples of more diverse skill levels would help to test this hypothesis (i.e., expert-novice or skill-group paradigms: Farrow & Abernethy, 2003).

Despite the ambiguous warm-up effect noted, this study produced a number of expected results, which to some degree speak to the validity and fidelity of our experimental set-up. With respect to the second hypothesis, gaze behavior and decision-making findings were of a predictable nature. For instance, pitch type predictions were a point of emphasis as the ability to discern a fastball from a curveball or change-up significantly impacts the chances of successfully striking an approaching pitch (Müller & Fadde, 2016). This sample demonstrated their advanced pitch recognition skill as all players predicted fastballs more accurately than curveballs and changeups (Figure 2). In addition, when considering playing experience as an independent variable, the distinction in gaze behavior and decision-making proficiency was apparent and expected. Tier one players totaled a higher number of release point fixations (Figure 3), spent a higher percentage of time fixating on task relevant areas (Table 1), and made significantly more total correct predictions. As such, their classification by tier appears to be appropriate (i.e., convergent validity).

In relation to effects that were anticipated, handedness appeared to be the most substantial. It is well supported that batters facing opposite-handed pitchers (i.e., left-handed batter vs right-handed pitcher) have an advantage over like-handed batters (Goldstein & Young, 1996). The left-handed batters used in this study supported this notion as they were able to predict fastballs and curveballs more accurately than the right-handed batters (Figure 2). Interestingly, a lack of a general handedness effect in the major gaze behavior analyses—TtRPFix, Fix*f*, and release point fixations—suggests that these variables do not adequately capture the advantage of being opposite-handed in interceptive sports, specifically in a visual context. Perhaps the advantage of being opposite-handed in baseball hitting is gained during the release of the pitch (i.e., opposite-handed batters naturally assume an advantageous head or gaze orientation), post-release of the pitch (i.e., during ball flight), or is attributed to other factors. Indeed, stability of left-handed prevalence generationally—particularly in interceptive/interactive sports—is well documented (Baker & Schorer, 2013;

Schorer et al., 2012; Loffing et al., 2012), with common explanations including perceptual frequency effects (Hagemann, 2009), unfamiliar playing strategies (Coren, 1993), and even weaker lateralization of the brain hemispheres (Grouios, 2004). While some combination of these effects may explain the noted handedness advantage in this study, the exact mechanism is unclear and could provide an avenue for future scientific inquiry. Empirical investigations—such as comparing the ball flight visual search strategies of opposite-handed hitters to like-handed batters (relative to the handedness of the pitcher/bowler), or the ability of hitters to deduce spin rates and axes from pitch grip and/or ball flight information—would help address this current gap in the literature.

Limitations and Future Research

While the current study explored a novel concept in high performance baseball players, future research should address some notable limitations. First, no general (knowledge of results), haptic, or audio feedback was provided to the athletes after they completed a swing. Participants may have used feedback, such as vibration of the bat (Carello et al., 1999) or the sound of bat-ball contact (Gray, 2009a), to determine the veracity of their predictions. One potential resolution moving forward may be to provide different forms of feedback to batters (for research designs that include haptic feedback, see: Carello et al., 1999; Gray, 2009a; Gray, 2017). Additionally, the simulation in this study was not designed to contain situational probabilities, which decreased the representativeness of the task. In competition, a batter's swing is significantly influenced by previous pitches and the situation (Gray, 2002). The use of situational probabilities has been demonstrated empirically in experienced baseball (Gray & Cañal-Bruland, 2018) and tennis (Farrow & Reid, 2012) players. However, this would be difficult to implement in a laboratory setting as participants would likely differ in their approach to certain situations (i.e., some batters may prefer to hit change-ups instead of curveballs). Notably, an oversight of the current study was that the occlusion manipulations were not randomized across trials, which made it difficult to distinguish between the acute influence of de-coupled warm-up and the occlusion difficulty. Addressing this limitation is of paramount importance and should be a priority in future studies.

The use of a projection screen, instead of a live pitcher or virtual environment, is another possible limitation to this study. Batters may not have been immersed to the degree they would be in the field. Future research on baseball batters may benefit from more immersive atmospheres or technologically advanced study designs (Gray, 2002, 2009a, 2017). Finally, a lack of baseline values and the modest sample size (N = 28) may suggest that our statistical comparisons were underpowered. A post hoc power calculation revealed that in order to detect a warm-up effect in the pitch type predictions with our observed effect size (η_p^2 = .11), a total sample size of approximately 93 would be needed. Theoretically, it would be ideal to have this many participants and baseline information to compare how the performance data may have differed after completing a warm-up drill. However, this sample consisted of high-performance athletes with intensive schedules, which posed a significant obstacle for recruitment and the collection of just one trial.

There is also a need for more longitudinal studies in this area. For example, Gray (2017) constructed a 6-week training intervention study where performance in virtual, on-field practice, and league competition environments were assessed. This study also tracked the athletes' highest level of competition achieved for five years after the intervention. Study designs of this nature, while costly, allow the researcher to assess more accurately the near and far transfer of the training intervention. A final and perhaps most intriguing direction for future research may lie within recalibration skill of the sensorimotor network. If the sample in this study did indeed exhibit a skill in recalibration, a prudent first step may be a replicative study or a cogent expert-novice design that addresses our aforementioned limitations.

Conclusion

This study sought to explore the acute influence that unrepresentative PWU drills may have on the decision-making and gaze behavior of advanced baseball players. Although de-coupled practice has led to undesirable movement patterns in previous research (Davids et al., 2001; Pinder et al., 2009; Reid et al., 2010), no statistically significant warm-up condition effects were noted in this study. However, the athletes' familiarity with these unrepresentative tasks and a possible skill in recalibration may explain this finding. This was demonstrated by the quicker release point fixations for the participants who completed more representative tasks followed by a regression to the mean for all warm-up conditions. Results also support expertise research of perceptual-cognitive skill in high performance batters (Kato & Fukuda, 2002; McRobert et al., 2011; Takeuchi & Inomata, 2009) as more experienced participants demonstrated significantly better decision-making and gaze behavior abilities than lesser experienced participants. Future research should explore the influence that unrepresentative PWU may have on the decision-making and gaze behavior of more novice athletes to learn more about the development of these key perceptual-cognitive skills.

End Notes

1. For an article about the sign stealing scandal in the MLB, see https://www.mlb.com/news/astros-sign-stealing-penalty.
2. The SensoMotoric Instruments Mobile Eye Tracker was programmed to film external video with a sampling rate of 120 Hertz, and had a gaze tracking range of 80° horizontal and 60° vertical.

Acknowledgement

The authors would like to thank Ryan Foley for his invaluable assistance in creating the experimental set-up for the study.

Authors' Declarations

The authors declare that there are no personal or financial conflicts of interest regarding the research in this article.

The authors declare that they conducted the research reported in this article in accordance with the Ethical Principles of the Journal of Expertise.

The authors declare that they are not able to make the dataset publicly available but are able to provide it upon request.

ORCID iDs

Matthew McCue
https://orcid.org/0000-0002-3440-0833

Nick Wattie
https://orcid.org/0000-0003-2623-000X

References

Abernethy, B., & Russell, D. (1984). Advance cue utilisation by skilled cricket batsmen. *Australian Journal of Science and Medicine in Sport*, *16*(2), 2-10.

Adair, R. K. (1995). The physics of baseball. *Physics Today, 48*(5), 26-31.

Andersson, R., Nyström, M., & Holmqvist, K. (2010). Sampling frequency and eye-tracking measures: how speed affects durations, latencies, and more. *Journal of Eye Movement Research, 3*(3), 6.

Araújo, D., Davids, K., & Passos, P. (2007). Ecological validity, representative design, and correspondence between experimental task constraints and behavioral setting: Comment on. *Ecological Psychology*, *19*(1), 69-78.

Baker, J., & Schorer, J. (2013). The Southpaw advantage?: Lateral preference in mixed martial arts. *PloS one*, *8*(11), e79793.

Baker, J., Wattie, N., & Schorer, J. (2015). Defining expertise: A taxonomy of skill levels for research in skill acquisition and expertise. In J. Baker & D. Farrow (Eds.), *The Routledge Handbook of Sport Expertise* (pp. 145-155). London: Routledge.

Bard, C., & Fleury, M. (1976). Analysis of visual search activity during sport problem situations. *Journal of Human Movement Studies, 3*(2), 214-222.

Brand, M. T., & de Oliveira, R. F. (2017).

Recalibration in functional perceptual-motor tasks: A systematic review. *Human Movement Science, 56,* 54-70.

Carello, C., Thuot, S., Anderson, K. L., & Turvey, M. (1999). Perceiving the sweet spot. *Perception, 28*(3), 307-320.

Castaneda, B., & Gray, R. (2007). Effects of focus of attention on baseball batting performance in players of differing skill levels. *Journal of Sport and Exercise Psychology, 29*(1), 60-77.

Coren, S. (1993). Left Hander: Everything you need to know about left-handedness. John Murray.

Davids, K., Kingsbury, D., Bennett, S., & Handford, C. (2001). Information-movement coupling: Implications for the organization of research and practice during acquisition of self-paced extrinsic timing skills. *Journal of Sports Sciences, 19*(2), 117-127.

Farrow, D., & Abernethy, B. (2003). Do expertise and the degree of perception-action coupling affect natural anticipatory performance? *Perception, 32*(9), 1127-1139.

Farrow, D., & Reid, M. (2012). The contribution of situational probability information to anticipatory skill. *Journal of Science and Medicine in Sport, 15*(4), 368-373.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175-191.

Goldstein, S. R., & Young, C. A. (1996). " Evolutionary" stable strategy of handedness in major league baseball. *Journal of Comparative Psychology, 110*(2), 164.

Gray, R. (2002). Behavior of college baseball players in a virtual batting task. *Journal of Experimental Psychology: Human Perception and Performance, 28*(5), 1131.

Gray, R. (2009a). How do batters use visual, auditory, and tactile information about the success of a baseball swing? *Research Quarterly for Exercise and Sport, 80*(3), 491-501.

Gray, R. (2009b). Intercepting moving objects: Fundamental principles learned from baseball. *Reviews of Human Factors and Ergonomics, 5*(1), 114-139.

Gray, R. (2009c). A model of motor inhibition for a complex skill: Baseball batting. *Journal of Experimental Psychology: Applied, 15*(2), 91.

Gray, R. (2017). Transfer of Training from Virtual to Real Baseball Batting. *Frontiers in Psychology, 8*(2183). doi:10.3389/fpsyg.2017.02183

Gray, R., & Cañal-Bruland, R. (2018). Integrating visual trajectory and probabilistic information in baseball batting. *Psychology of Sport and Exercise, 36*, 123-131.

Grouios, G. (2004). Motoric dominance and sporting excellence: Training versus heredity. *Perceptual and Motor Skills*, 98(1), 53-66.

Hagemann, N. (2009). The advantage of being left-handed in interactive sports. *Attention, Perception, & Psychophysics*, 71(7), 1641-1648.

Hall, B. (2019). Why Traditional MLB Batting Practice is Dying a Slow Death. Retrieved from https://www.stack.com/a/why-traditional-mlb-batting-practice-is-dying-a-slow-death

Hall, K. G., Domingues, D. A., & Cavazos, R. (1994). Contextual interference effects with skilled baseball players. *Perceptual and Motor Skills, 78*(3), 835-841.

Hubbard, A. W., & Seng, C. N. (1954). Visual movements of batters. *Research Quarterly. American Association for Health, Physical Education and Recreation, 25*(1), 42-57.

Kato, T., & Fukuda, T. (2002). Visual search strategies of baseball batters: Eye movements during the preparatory phase of batting. *Perceptual and Motor Skills, 94*(2), 380-386.

Krause, L., Farrow, D., Reid, M., Buszard, T., & Pinder, R. (2017). Helping coaches apply the principles of representative learning design: Validation of a tennis specific practice assessment tool. *Journal of Sports Sciences,* 1-10.

Kredel, R., Vater, C., Klostermann, A., & Hossner, E.-J. (2017). Eye-Tracking Technology and the Dynamics of Natural Gaze Behavior in Sports: A Systematic Review of 40 Years of Research. *Frontiers in Psychology, 8*(1845).

doi:10.3389/fpsyg.2017.01845

Krueger, C., & Tian, L. (2004). A comparison of the general linear mixed model and repeated measures ANOVA using a dataset with multiple missing data points. *Biological Research for Nursing, 6*(2), 151-157.

Loffing, F., Schorer, J., Hagemann, N., & Baker, J. (2012). On the advantage of being left-handed in volleyball: Further evidence of the specificity of skilled visual perception. *Attention, Perception, & Psychophysics, 74*(2), 446-453.

Mann, D. T., Williams, A. M., Ward, P., & Janelle, C. M. (2007). Perceptual-cognitive expertise in sport: A meta-analysis. *Journal of Sport and Exercise Psychology, 29*(4), 457-478.

Marteniuk, R. G. (1976). *Information processing in motor skills*: Holt, Rinehart and Winston.

McPherson, S. L. (1993). The influence of player experience on problem solving during batting preparation in baseball. *Journal of Sport and Exercise Psychology, 15*(3), 304-325.

McRobert, A. P., Ward, P., Eccles, D. W., & Williams, A. M. (2011). The effect of manipulating context-specific information on perceptual–cognitive processes during a simulated anticipation task. *British Journal of Psychology, 102*(3), 519-534.

Müller, S., & Fadde, P. J. (2016). The relationship between visual anticipation and baseball batting game statistics. *Journal of Applied Sport Psychology, 28*(1), 49-61.

Official Baseball Rules 184 (2018).

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *Journal of Sport and Exercise Psychology, 33*(1), 146-155.

Pinder, R. A., Renshaw, I., & Davids, K. (2009). Information–movement coupling in developing cricketers under changing ecological practice constraints. *Human Movement Science, 28*(4), 468-479.

Pinder, R. A., Renshaw, I., Davids, K., & Kerhervé, H. (2011). Principles for the use of ball projection machines in elite and developmental sport programmes. *Sports Medicine, 41*(10), 793-800.

Reid, M., Whiteside, D., & Elliott, B. (2010). Effect of skill decomposition on racket and ball kinematics of the elite junior tennis serve. *Sports Biomechanics, 9*(4), 296-303.

Rieser, J. J., Pick, H. L., Ashmead, D. H., & Garing, A. E. (1995). Calibration of human locomotion and models of perceptual-motor organization. *Journal of Experimental Psychology: Human Perception and Performance, 21*(3), 480.

Schorer, J., Loffing, F., Hagemann, N., & Baker, J. (2012). Human handedness in interactive situations: Negative perceptual frequency effects can be reversed! *Journal of Sports Sciences, 30*(5), 507-513.

Scott, S., & Gray, R. (2010). Switching tools: Perceptual-motor recalibration to weight changes. *Experimental Brain Rsesearch, 201*(2), 177-189.

Sullivan, J. (2019). The Velocity Surge Has Plateaued. sssssRetrieved from https://blogs.fangraphs.com/the-velocity-surge-has-plateaued/

Takeuchi, T., & Inomata, K. (2009). Visual search strategies and decision making in baseball batting. *Perceptual and Motor Skills, 108*(3), 971-980E.

Waldstein, D. (2012). Cherished Tradition or a Colossal Waste of Time? *The New York Times*. Retrieved from https://www.nytimes.com/2012/08/17/sports/baseball/batting-practice-cherished-tradition-or-colossal-waste-of-time.html?module=inline

Submitted: 17 Month 2020
Revision submitted: 17 February 2021
Accepted: 19 Month 2021