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Effects of Focus of Attention on Baseball Batting Performance in Players of Differing Skill Levels

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This study addressed the question, what should baseball players focus their attention on while batting? Less-skilled and highly skilled (college) baseball players participated in four dual-task conditions in a baseball batting simulation: two that directed attention to skill execution (*skill/internal* [movement of the hands] and *skill/external* [movement of the bat]) and two that directed attention to the environment (*environmental/irrelevant* [auditory tones] and *environmental/external* [the ball leaving the bat]). Batting performance for highly skilled players was best in the environmental/external condition and worst in the skill/internal condition. Performance of less-skilled batters was significantly better in the two skill conditions than in either of the two environmental conditions. We conclude that the optimal focus of attention for highly skilled batters is one that does not disrupt proceduralized knowledge and permits attention to the perceptual effect of the action, whereas the optimal focus of attention for less-skilled batters is one that allows attention to the step-by-step execution of the swing.

Previous research on baseball batting has focused primarily on how a batter uses perceptual cues to predict the time of arrival of a pitch and where it will be when it crosses the plate (e.g., Bahill & Karnavas, 1993; Burroughs, 1984), swing biomechanics and motor control (e.g., Bahill & LaRitz, 1984; Welch, Banks, Cook, & Draovitch, 1995), and the physics of the ball flight and bat-ball contact (e.g., Adair, 1990; Watts & Bahill, 1991). Although these lines of research are clearly important for understanding this complex behavior, they do not address an issue that most coaches and players will say is crucial to being a good hitter: the "mental aspect" of baseball batting. According to Ted Williams, whom many consider to be the greatest hitter ever, "proper thinking is 50 percent of effective hitting" (Williams &Underwood, 1970). Recently, researchers have attempted to "get inside the batter's head" to understand the cognitive processes involved in baseball batting, such as deciding whether the upcoming pitch will be a fastball or a curveball (Gray, 2002a), visual search strategies used by baseball batters (Kato & Fukuda, 2002), and changes in batting strategy associated with pressure and batting slumps (Gray, 2004). One particularly interesting and unresolved question

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that has come from this recent work is, what should baseball players focus their attention on while batting?

An examination of the experimental research reveals that the answer to this question depends largely on how researchers have defined the different possible attentional foci a skilled performer could have. One group of studies has compared *skill-focused attention* with *environmentally focused attention*. Skill-focused attention is attention to any aspect of the motor action (e.g., the position of the limbs or movement of the bat). Environmentally focused attention is attention to anything in the environment not directly involved in skill execution (e.g., the position of infielders or sounds from the crowd). Gray (2004) compared these two types of attention using a baseball batting simulation. The main finding was that the performance of expert (college) baseball players was degraded relative to baseline performance in the skill-focused attention condition (attending to the direction of bat movement). Analysis of batting kinematics for experts revealed that this performance degradation was at least partially due to the fact that skill-focused attention interfered with the sequencing and timing of the motor responses involved in swinging a baseball bat consistent with idea of "dechunking," proposed by Masters (1992). Performance was not significantly different from baseline for experts in the environmentally focused attention condition (attending to the frequency of auditory tones). Performance for novices was degraded in the environmentally focused attention condition and improved in the skill-focused attention relative to baseline performance. Beilock, Carr, and colleagues (Beilock, Carr, MacMahon, & Starkes, 2002; Beilock, Wierenga, & Carr, 2002) have reported similar findings for both golf putting and soccer ball dribbling. In a recent study, Beilock, Bertenthal, McCoy, and Carr (2004) found that expert golfers were more accurate when instructed to putt at a faster speed compared to instructions that emphasized accuracy, whereas novice golfers showed the opposite pattern of results. The authors argue that these effects occurred because speed constraints do not allow sufficient time for skill-focused attention. All these findings are consistent with the dominant theories of skill acquisition (Fitts & Posner, 1967; Anderson, 1982), which have proposed that skill execution in novices requires attention to be paid to each component stage of the motor act (utilizing declarative knowledge), whereas skill execution in experts is based on fast, efficient control procedures that can function largely without the assistance of working memory or attention (proceduralized knowledge).

A separate group of studies examining the relationship between attention and skilled performance has compared *internally focused attention* with *externally focused attention.* In these studies, internally focused attention is defined as attention to the movement of part of one's own body during skill execution (e.g., movement of the hands or the lead foot during a baseball swing), whereas externally focused attention is attention directed to the effect one's body movement has on the external environment (e.g., the movement of the bat or the flight of the ball leaving the bat, Wulf & Prinz, 2001). To our knowledge there is no previous research that has compared these two types of attention for baseball batting; however, the findings from research on other sports have important implications for baseball. For example, Wulf and colleagues have shown that externally focused attention results in better performance and faster learning as compared to internally focused attention for sports including performance on a ski simulator (Wulf, Höss, & Prinz, 1998), golf (Wulf, Lauterbach, & Toole, 1999), and tennis (Maddox, Wulf, & Wright, 1999).

Furthermore, it has been shown that, when externally focused attention is directed to a movement effect that is a larger distance from the body, performance and learning rate improve even further. For example, McNevin, Shea, and Wulf (2003) found that in a balancing task performance was better when participants directed their attention to the movement of markers that were further from their feet as opposed to markers that were placed close to their feet (note that these are both examples of externally focused attention). This distance effect is consistent with the constrained action hypothesis (Wulf, McNevin, & Shea, 2001), which proposes that when performers attend to their body movement or a movement effect that is close to their body they tend to actively intervene with skill execution, which results in a disruption of automaticity.

Most of the early studies by Wulf and colleagues involved novice participants. However, more recently it has been shown that these effects can also occur in experienced athletes. Wulf, Gärtner, McConnel, and Schwarz (2002) reported greater accuracy for serves made by experienced volleyball players and for passes made by experienced soccer players when feedback was given that encouraged externally focused attention. Perkins-Ceccato, Passmore, and Lee (2003) recently reported that, for golf pitch shots, expert golfers performed better in an externally focused attention condition (attending to where the ball landed) as compared to internally focused attention condition (attending to the form and force of one's swing). Contrary to the work by Wulf and colleagues, the pattern of results was exactly opposite for novice golfers: Performance was better in the internally focused attention condition. However, it should be noted that it is not clear whether the instructions used in the internally focused attention condition actually induced an internal focus for novices; that is, the instruction to monitor the force of the swing may have led participants to attend to the impact of the club on the ball, which would constitute an external focus of attention.

So how do these two lines of research compare and what predictions do each make about the optimal attentional focus for baseball batting? This can be understood by more closely examining two comparisons that differentiate the two approaches. The first is attending to the movement of a part of one's body during a swing (e.g., the hands or feet) versus attending to the movement of the bat. On one hand, in the account forwarded by Beilock, Gray, and colleagues, these are both examples of skill-focused attention and therefore they should be equally detrimental to expert performance (by disrupting proceduralized knowledge) and equally beneficial to novice performance (by increasing attention to the component steps of skill execution). Therefore, this account predicts there should be no difference in batting performance in these two attention conditions for both experts and novices. On the other hand, in the account forwarded by Wulf and colleagues, attention to body movement is a type of internally focused attention whereas attention to bat movement is a type of externally focused attention. Therefore, performance should be better when attending to bat movement than when attending to hand movement for both novice and expert performers. A second comparison that differentiates these two approaches is attending to the ball leaving the bat versus attending to an irrelevant environmental stimulus (e.g., sounds from the crowd). In the Beilock, Gray, and colleagues account, these are both types of environmentally focused attention (i.e., neither involves attending to the motor action) and therefore they should be equally beneficial for expert performers (because they allow proceduralized knowledge to operate uninterrupted) and equally detrimental to novice performers (because they draw attention away from skill execution). Therefore, this account would predict no differences in batting performance in these two attention conditions for both novices and experts. In the Wulf and colleagues account, attending to the ball leaving the bat is a type of externally focused attention. Attention to an irrelevant distracter is neither an internal or an external focus (and is not discussed in the work by Wulf and colleagues); however, from their previous work it would be reasonable to expect that performance would be better when attention is directed to the ball leaving the bat as opposed to an irrelevant stimulus for both novices and experts.

Before discussing how these approaches were compared in the present study, there is another important difference between these two lines of research that must be considered, namely, the differences in the experimental methodology used to direct attention. In the work by Wulf and colleagues, the focus of attention is varied across conditions through the use of verbal instructions (e.g., participants are told to attend to the movement of a body part in one condition and told to attend to the ball leaving the club in another condition). This instruction paradigm has an important limitation (see Gray, 2004, for a detailed discussion): There is no way to check whether participants actually directed their attention to the instructed location. In order to address this limitation, Beilock, Gray, and colleagues have used a dual-task methodology in which secondary tasks are used to direct attention to specific aspects of the task (e.g., see Gray, 2004). One of the main advantages of this dual-task approach is that it is possible to determine whether or not participants directed attention to the specified locations by measuring the accuracy of the secondary task responses. However, it could also be argued that performing a dual-task while batting is unnatural and may be more demanding than simply following instructions. Even though both paradigms are accepted methods for studying attention, this difference in task demands limits the direct comparability between studies using dual-task methodologies and previous studies examining internal versus external focus effects. This issue is discussed in more detail below.

The primary goal of the present study was to examine the two comparisons between attentional foci (described above) in which the *skill* vs. *environment* and *internal* vs. *external* accounts make different performance predictions. To reiterate, these two comparisons are (1) attending hand movement vs. attending bat movement and (2) attending the ball leaving the bat vs. attending an irrelevant environmental stimulus. In addition, because almost all of the research comparing *internally focused* vs. *externally focused* attention has had no formal manipulation checks to ensure that participants actually directed their focus of attention to the instructed location (discussed in Gray, 2004), a secondary goal of the present study was to provide a more rigorous test of *internally focused* vs. *externally focused* attention effects report by Wulf and colleagues using a dual-task methodology.

Methods

Participants

Sixteen male baseball players participated in the experiment. The eight highly skilled participants (competitive playing experience, $M = 13.2$, $SE = 0.7$ year; age, $M = 19.5$, $SE = 0.5$ year) played for a college baseball team affiliated with the National Junior College Athletic Association (NJCAA). The eight less-skilled participants were not currently playing college baseball (competitive playing experience, $M = 6.1$, $SE = 1.1$ years; age, $M = 21.9$, $SE = 0.9$ year). All participants were paid an hourly rate, signed informed consent forms, and were naïve to the aims of the experiment until they were debriefed at the end. The work reported here was approved by the institutional ethics review board of Arizona State University.

Apparatus

The baseball batting simulation used in the present study was a modified version of the simulation used in several previous experiments (Gray, 2002a, 2002b, 2004). Participants swung a baseball bat at a simulated approaching baseball. The simulated ball was an off-white sphere texture-mapped with red laces. The image of the ball, a pitcher, and the playing field (shown in Figure 1) were projected onto a screen, 2.11 m wide × 1.47 m tall, using a Proxima 6850+ LCD projector. Batters stood beside a standard 0.45- × 0.45-m home plate that was placed on the floor 2.5 m in front of the screen. The area around the plate and the area between the plate and the screen were covered with green indoor/outdoor carpet. Each batter stood on the side of the plate from which they most commonly batted during actual games. Mounted on the end of the bat (Louisville Slugger Tee Ball bat; 25 inches in length) was a sensor from a Fastrak (Polhemus) position tracker. The x, y, and z positioning of the end of the bat was recorded at a rate of 120 Hz.

As shown in Figure 1, a sensation of motion toward the batter was created by increasing the angular size of the ball. The vertical position of the ball on the display was changed to simulate the drop of the ball as it approached the batter. The only force affecting the flight of the simulated ball was gravity (e.g., we ignored the effects of air resistance and spin on the ball's flight). The height of the simulated pitch $Z(t)$ was changed according to

$$Z(t) = -1/2 \cdot g \cdot t^2$$

where g is acceleration of gravity (9.8 m/s). All pitches were strikes and traveled down the center of the plate. Although this is a simplified version of real baseball batting, where there can also be a large variation in the lateral position of the ball when it crosses the plate, previous research has shown that the judgment of pitch height is the most difficult for the batter and is the cause of the majority of performance errors (Bahill & Karnavas, 1993; Gray, 2002a). Pitch speed was varied randomly from trial to trial and ranged from 30 to 40 m/s (67–90 mph). This range of speeds resulted in a large variation in the height of the ball when it crossed the plate.

Each trial began with a 10-s view of the playing field and the virtual pitcher in the starting pose (Figure 1, top panel). During the first 8 s of this period, a probe (a small yellow cone) was displayed on the field for reasons that will be described below. The probe was always located at the bottom of the screen but its lateral position was varied randomly from trial to trial. The simulated pitcher then executed a simulated pitching delivery that lasted roughly 3 s before the virtual ball approached the batter. The position of the ball in the simulation was compared with the recording of bat position in real time in order to detect collisions between the bat and ball. The estimated static positional precision of our tracking system (<0.2 mm) was derived from the standard deviation of 50 samples with the sensor

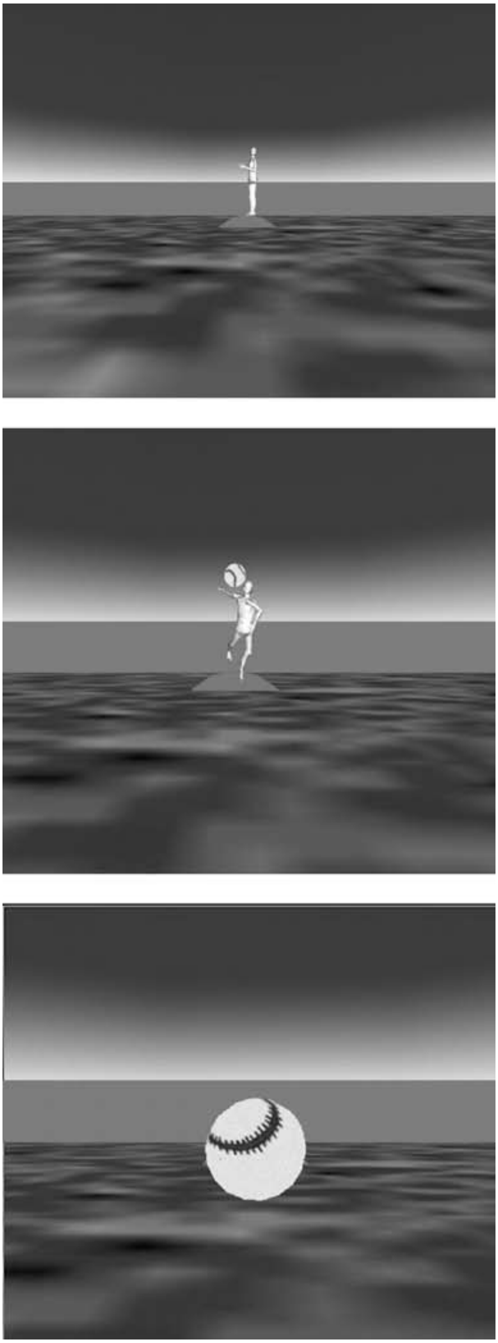

Figure 1 — Visual display in the batting simulation.

at a constant position. The dynamic precision of the system (<1 mm) was estimated using the method described by Tresilian and Lonergan (2002).

Batters received auditory and visual feedback about the success of their swing. The timing of presentation of this feedback was as follows. If no contact between the bat and the ball occurred, an audio file of an umpire saying "strike" was played over a loudspeaker. If contact between bat and ball was detected, the sound of the "crack" of a bat was played at the instant contact was detected and the location of the bat, bat speed, ball speed, and bat angle were used to visually simulate the ball flying off the bat (i.e., moving away from the batter) into the simulated playing field. For ball trajectories into foul territory (i.e., outside the simulated playing field), an audio file of an umpire saying "foul ball" was played. For home runs (fair balls that traveled further than 107 m [350 feet]), an audio file of an announcer's home run call from a real game was played.

Procedure

In all conditions, participants were informed that the primary objective of the task was to hit the virtual ball. In the event that participants inquired about directions for swinging the bat, the experimenter instructed the participants to swing as they normally would in a game situation. Participants were also told that their baseball batting performance would be measured. The four different attention conditions used were as follows.

Skill/Internal Focus. In this condition, attention was directed to execution (*skill*) and to movement of the body (*internal*). Participants were instructed to judge whether their hands were moving upward or downward at the instant in time that an auditory tone was presented, while simultaneously engaging in the batting task. They were further instructed not to look at their hands during the swing in order to make their judgment but rather look at the things they normally look at when executing a swing.[1] Participants were instructed to make their forced-choice judgment of "up" or "down" after the swing and feedback were completed and to use as much time as needed to make their response. The experimenter recorded participants' verbal responses. Response accuracy was calculated by using the sign of the vertical hand velocity computed from the motion tracker output (Gray, 2004). Auditory tones had either a high (500 Hz) or low (250 Hz) frequency chosen randomly on each trial for reasons that are described below. Participants were instructed to respond in the same manner for both tone frequencies. Tones were presented for a duration of 100 ms and occurred at a random time between 300 and 800 ms after the virtual baseball appeared on the screen. This range was chosen because in previous studies we have found that the mean swing duration (measured from onset of bat movement) is roughly 500 ms and the onset of the swing occurs at roughly 300 ms after pitch release (Gray, 2002a).

Skill/External Focus. In this condition, attention was directed to execution (*skill*) and to an effect of the batter's body movement (*external*). This condition was identical to the skill/internal condition except that participants were instructed to judge the direction of the bat's movement (either "upward" or "downward") at the instant in time the auditory tone was presented, while simultaneously engaging in the batting task. They were again instructed to look at the things they normally look at when executing a swing. Responses were again made after the swing and feedback were completed. The vertical velocity of the end of the bat was used to assess response accuracy.

Environmental/External Focus. In this condition, attention was directed away from skill execution (*environmental*) and to an effect of the batter's body movement (*external).* In this condition, batters made a judgment about the ball leaving their bat. Following completion of the swing and presentation of feedback, batters were instructed to judge whether the simulated ball traveled to the right or to the left of the probe location shown in the pre-swing interval (see above). To allow for direct comparison with the other conditions, the auditory tones were presented as described above but the batter was instructed to ignore them in this case.

Environmental/Irrelevant Focus. In this condition, attention was directed away from skill execution (*environmental*) and away from an effect of the batter's body movement (*irrelevant*). This condition was identical to the skill/internal condition except that participants were asked to judge whether the frequency of the tone was high or low. Responses were again made after the swing and feedback were completed. Prior to beginning this condition, the experimenter played a sound clip of both the low and high tones so participants had examples of the stimuli they would be hearing.

It should be noted that for all four attention conditions the stimuli presented to the participant were identical (e.g., the tones were always present and the probe was always displayed prior to the pitch being delivered), only the instructions about what they should attend to were different. Participants completed two blocks of 20 practice trials. Following practice, two blocks of 20 trials were completed for each of the four conditions. Participants were given the option of taking short breaks between the conditions. All batters also completed two blocks of 20 trials of a control condition in which they were instructed to ignore the tones and probe and were not required to perform a secondary task. The sequence of the four attention conditions and the control condition were counterbalanced using a Latin square design to control for any order effects. The order of conditions for each participant is shown in Table 1.

Data Analysis

The mean temporal swing error (MTE) was used as the batting performance measure for all five conditions by less-skilled and highly skilled players. The MTE is defined as the absolute difference between the time when the ball crossed the front of the plate and the time the minimum bat height occurred (see Gray, 2002a, for further details about this variable). It has previously been shown that this variable is significantly correlated with the batting average and on-base percentage (taken from league statistics) of expert baseball players (Gray, 2004), suggesting that it is a measure that has good external validity.

The MTE data were analyzed using a 2 × 5 (Skill Level × Condition) mixed-factor analysis of variance (ANOVA). Eight planned orthogonal comparisons were made using the error term from the omnibus F test. The first four were key comparisons that differentiate the two theoretical approaches described above: (1) the skill/external focus condition versus the skill/internal focus condition in highly

Table 1 Experimental Condition Orders

	Less-skilled					Highly skilled			
	Order 1	**Order 2**	**Order 3**	**Order 4**		**Order 1**	**Order 2**	**Order 3**	**Order 4**
Subject 1	C2	C4	C1	C3	Subject 1	C4	C1	C3	C2
Subject 2	C1	C2	C4	C3	Subject 2	C1	C3	C4	C2
Subject 3	C2	C3	C1	C4	Subject 3	C3	C4	C2	C1
Subject 4	C1	C3	C4	C2	Subject 4	C1	C2	C4	C3
Subject 5	C4	C2	C3	C1	Subject 5	C2	C3	C1	C4
Subject 6	C4	C1	C3	C2	Subject 6	C3	C1	C2	C4
Subject 7	C3	C1	C2	C4	Subject 7	C2	C4	C1	C3
Subject 8	C3	C4	C2	C1	Subject 8	C4	C2	C3	C1

Note. C1 = skill/internal, C2 = skill/external, C3 = environmental/external, and C4 = environmental/irrelevant.

skilled players, (2) the skill/external focus condition versus the skill/internal focus condition in less-skilled players, (3) the environmental/external focus versus the environmental/irrelevant focus conditions in highly skilled players, and (4) the environmental/external focus versus the environmental/irrelevant focus conditions in less-skilled players. The remaining four contrasts were designed to be orthogonal to those described above: (5) the mean of the two skill conditions vs. the mean of the two environmental conditions across skill level, (6) the mean of the two skill conditions vs. the mean of the two environmental conditions in highly skilled players, (7) the mean of the two skill conditions vs. the mean of the two environmental conditions in less-skilled players, and (8) the control condition in less-skilled players vs. the control condition in highly skilled players. Cohen's f statistic was used as an unbiased estimate of effect size (Cohen, 1988).

In order to make valid conclusions about the role of attention in skilled performance, it is important that researchers check that attention is actually directed to the intended location. One of the primary checks that can be done is to examine the response accuracy in the secondary task: If the task is sufficiently difficult and accuracy is high, one can assume that the participant is directing his or her attention to the intended location (Abernethy, 1988). Secondary task performance was quantified by calculating the percentage correct for each condition. These data were analyzed using a 2 × 4 ANOVA and the planned comparisons, 1 through 7, described above. Note that because the control condition did not involve a secondary task it was not included in this analysis.

Results

Batting Performance

Figure 2 shows the MTE for the four attention conditions. Open bars are for less-skilled players and filled bars are for highly skilled players. The omnibus ANOVA revealed significant main effects of skill level, $F(1, 14) = 47.3$, $p < 0.001$, $f = 0.76$, and condition, $F(4, 56) = 5.2$, $p < 0.01$, $f = 0.45$. A significant Condition × Skill-Level interaction was also found, $F(4, 56) = 20.9$, $p < 0.001$, $f = 0.9$. The effect sizes were large ($f > 0.4$) for all of these effects (Cohen, 1988). We next discuss the results from our planned comparisons.

1. For highly skilled players, the MTE in the skill/internal condition was significantly higher than the MTE in the skill/external condition, $t(7) = 3.2$, $p < 0.01$, $f = 0.23$.
2. For less-skilled players, there was no significant difference between the MTE in the skill/internal condition and the skill/external condition, $t(7) = 0.3$, $p > 0.5$, $f = 0.25$.
3. For highly skilled players, the MTE in the environmental/irrelevant condition was significantly higher than in the environmental/external, $t(7) = 5.6$, $p < 0.001$, $f = 0.3$.
4. For less-skilled players, the MTE in the environmental/irrelevant condition was significantly higher than in the environmental/external condition, $t(7) = 2.0$, $p < 0.05$, $f = 0.27$.

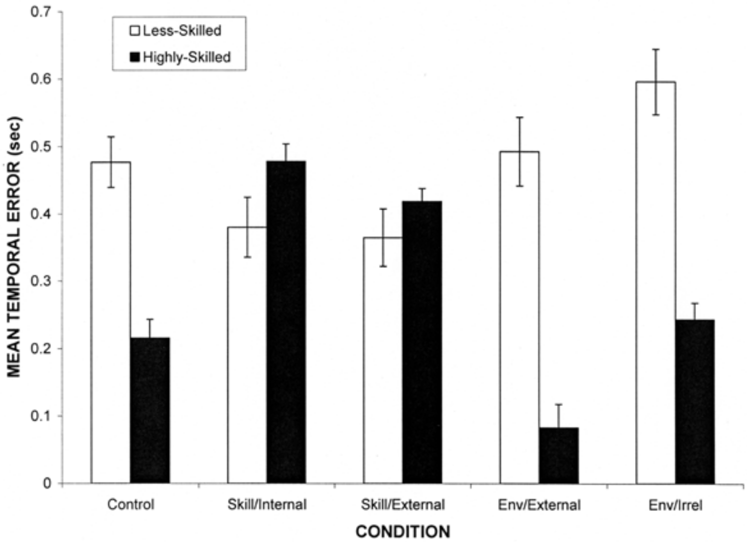

Figure 2 — Mean temporal batting errors for less-skilled and highly skilled players in the four attention conditions: skill/internal, skill/external, environmental (Env)/external, and environmental/irrelevant (Irrel). Error bars represent standard errors.

5. A comparison of the combined mean of the two skill conditions versus the combined mean of the two environmental conditions revealed a significant Condition × Skill-Level interaction, $t(14) = 8.2$, $p < 0.001$, $f = 0.79$.
6. For highly skilled players, the mean MTE for the two skill conditions was significantly higher than the mean MTE for the two environmental conditions, $t(7) = 19.3$, $p < 0.001$, $f = 0.47$.
7. For less-skilled players, the mean MTE in the two skill conditions was significantly lower than the mean MTE for the two environmental conditions, $t(7) = 2.7$, $p < 0.05$, $f = 0.89$.
8. The mean MTE in the control condition was significantly higher for less-skilled players than for highly skilled players, $t(7) = 6.5$, $p < 0.001$, $f = 0.5$.

The effect sizes were medium ($f \approx 0.25$) for Comparisons 1, 2, 3, and 4 and were large for Comparisons 5–8 (Cohen, 1988).

Secondary Task Performance

Figure 3 shows the mean percentage correct for each of the secondary tasks for both less-skilled players and highly skilled players. Mean percentage correct was relatively high in all conditions (ranging from 71 to 96% for highly skilled players and 72 to 96% for less-skilled players), suggesting that the participants were directing their attention to the intended location in all conditions. The omnibus ANOVA revealed a significant main effect of condition, $F(3, 42) = 128.5$, $p < 0.001$, $f = 1.5$, and the planned comparisons revealed that the mean percentage accuracy in the two skill conditions was significantly lower than the mean percentage accuracy in

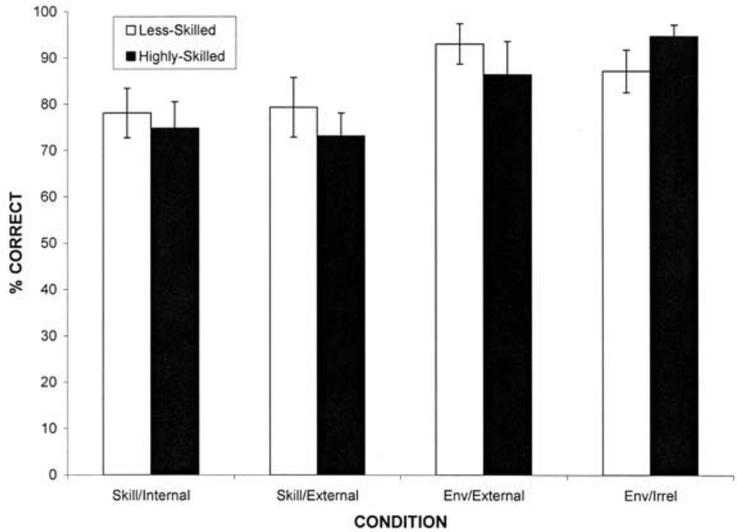

Figure 3 — Mean percentage correct for the secondary tasks in the four attention conditions for less-skilled and highly skilled players: skill/internal, skill/external, environmental (Env)/external, and environmental/irrelevant (Irrel). Error bars represent standard errors.

the two environmental conditions for both less-skilled players, $t(7) = 4.1, p < 0.05, f = 0.4$, and highly skilled players, $t(7) = 7.6, p < 0.01, f = 0.27$. None of the other statistical tests revealed significant results. Of particular importance to the present study is the fact that the key comparisons that differentiate the two theoretical approaches (Comparisons 1-4 described above) were not significant for secondary task accuracy, suggesting that differences in batting performance between these conditions were not due to a tradeoff between the primary and secondary task.

Discussion

The main theoretical goal of this study was to compare the opposing predictions of the two primary lines of research on attention and skilled performance. In general, the results of the present study were more consistent with the account forwarded by Wulf and colleagues with one notable exception. Consistent with Wulf and colleagues, batting performance was significantly better when attention was directed to the flight of the ball leaving the bat (environmental/external) than when it was directed to the an auditory tone (environmental/irrelevant) for both less-skilled players and highly skilled players. Also consistent with this account, batting performance was significantly better when highly skilled batters attended to the movement of their bat (skill/external) compared to when they attended to the movement of their hands (skill/internal). However, consistent with the predictions of Beilock, Gray, and colleagues, there was no significant difference in batting performance between the skill/external and skill/internal for less-skilled players. We next discuss these findings in an attempt to answer the practical question, what should highly skilled and less-skilled batters attend to?

What Should Highly Skilled Baseball Batters Attend To?

Shifting the focus of attention of the highly skilled batters in the present study through the use of secondary tasks greatly affected batting performance. From Figure 2 it can be seen that the order of conditions from worst to best was as follows: attending movement of the hands (skill/internal), attending movement of the bat (skill/external), attending auditory tones (environmental/irrelevant), and attending to the flight of the ball leaving the bat (environmental/external). Relative to the skill/internal condition, the mean change in MTE for the other three conditions was −7.2 ms, −24.0 ms, and −39.7 ms. These differences are quite substantial given that the margin for error for the speed range used in the present study was roughly 10–20 ms (Watts & Bahill, 1991). Clearly, attending to the right location is an important aspect of successful baseball batting. It can also be seen in Figure 2 that attending to skill execution (either *internal* or *external*) degraded batting performance relative to the control condition, whereas attending to the flight of the ball leaving the bat appeared to improve batting performance relative to the control condition. However, it is difficult to interpret the results from the control condition because we have no way of knowing what the batter was attending to in this case.

Why did attentional focus influence batting performance for highly skilled players? Our proposed explanation is shown in Table 2. Consistent with previous research by Beilock, Carr, and colleagues, in the present study we found that attention to skill execution (either internal or external of the body) in highly skilled players resulted in significantly worse performance as compared to attending to the information in the environment (either to the ball leaving the bat or to irrelevant auditory tones). We propose that this effect is due to the fact that when attention is directed away from skill execution, the motor control procedures that highly skilled players have developed through extensive practice can operate uninterrupted by conscious control (as first suggested by James, 1890).

However, consistent with the findings of Wulf et al. (2002) and Perkins-Ceccato et al. (2003), we also found that not all types of skill-focused attention are the same for expert performers. For our college players, batting performance was significantly better when attention was directed to an aspect of skill execution that was external

Table 2 Proposed Relationship Between Focus of Attention and Highly Skilled Performance

	Attentional Focus			
	Skill/ Internal	Skill/ External	Environmental/ External	Environmental/ Irrelevant
Allows proceduralized knowledge to operate uninterrupted	No	No	Yes	Yes
Strengthens link between actions and their perceivable effects	No	Yes	Yes	No

to the body (movement of the bat) as compared with attention to an aspect of skill execution that was internal to the body (movement of the hands). To our knowledge this is the first demonstration of this effect using an experimental design with attentional manipulation checks. As first discussed by Wulf and colleagues (reviewed in Wulf and Prinz, 2001), this effect is consistent with the common-coding theory of perception and action (Prinz, 1990). This theory suggests that actions are coded in terms of the perceivable effects they should generate. One's movements are determined by representations coding perceptible action effects, which automatically generate the motor codes that underlie the sequence of behaviors that will create the perceptible environmental changes. Therefore, attending the perceptual effect that one's movements have on the environment rather than the movements themselves should serve to strengthen this coding. A detailed explanation of these effects is also given by the "constrained action hypothesis" (Wulf, McNevin, & Shea, 2001) discussed above.

Finally, we found that not all forms of environmentally focused attention were equivalent for highly skilled batters. When attention was directed to the simulated ball leaving the bat (an external focus), performance was significantly better as compared to when attention was directed to information in the environment that was irrelevant to hitting (tone frequency). This finding is not consistent with an account forwarded by Beilock, Gray, and colleagues. We propose that this can again be understood in terms of common-coding theory. As shown in Table 2, although both of the environmental tasks used in the present study would prevent the interruption of procedural knowledge, the environmental/external condition has the additional advantage that it allows the connection between the action and its perceivable effects to be strengthened because the batter is attending to the movement effect instead of an irrelevant stimulus.

In interpreting the difference between our two environmental conditions, there is an important caveat that must be noted: not only did batters attend to different information in the environmental/external and environmental/irrelevant conditions, but they also presumably attended at different times during the action. Whereas the latter condition directed attention during the swing, the former directed attention to an event after the swing was complete (the ball leaving the bat). Therefore, it is possible that batting performance was better in the environmental/external condition not because there is an advantage in attending the movement effect but rather because the batter's attention was "freed-up" during swing execution. However, if attending to movement effects did not facilitate performance on its own, we would presumably not have found any difference between the two skill conditions because attention is required during the swing for both.

In summary, we would conclude that directing attention to the ball leaving the bat results in optimal performance for highly skilled baseball batters. As shown in Table 2, we propose that this focus of attention gives two benefits to the batter: (i) it does not interfere with proceduralized knowledge and (ii) it allows the link between the action and its perceivable effects to be strengthened. However, it should be noted that in the present study all pitches were strikes so that the batter swung on every trial. It is possible that the optimal attentional focus may be different if we used strikes and balls in our simulation and batters also had to decide whether or not to swing. We plan to investigate this in future research.

What Should Less-Skilled Baseball Batters Attend To?

As discussed in detail above, it has been shown for novices that directing attention toward the effect of one's movement results in better performance than when attention is directed to the movement itself (reviewed in Wulf and Prinz, 2001). Furthermore, as described above, it has been shown that for novices there appears to be an advantage to attending to a movement effect that is closer to the body than one that is distant (Wulf et al., 2000). In terms of the present study, these previous findings suggest that batting performance for less-skilled players should be significantly better in both the skill/external and environmental/external conditions than in the skill/internal and environmental/irrelevant conditions because the latter two conditions do not direct attention to a movement effect. Furthermore, performance should be better in the skill/external than the environmental/external condition because the former condition is directing attention to a movement effect that is closer to the body. From Figure 2 it can be seen that the present results were mostly inconsistent with these predictions. As would be predicted from the work of Wulf and colleagues, batting performance was better in the skill/external than in the environmental/external condition. However, inconsistent with these predictions, there was no significant difference between the skill/internal and skill/external conditions. In other words, we did not find a consistent advantage of an external focus of attention over an internal focus of attention for less-skilled players as has been reported in numerous previous studies by Wulf and colleagues. Instead, the present results appear to be more consistent with the proposal of Beilock, Gray, and colleagues that all forms of environmental attention (whether attention is directed to an action effect like the flight of the ball or to an irrelevant stimulus) are detrimental to performance by less-skilled players because successful skill execution at this stage of expertise requires attention to each of the component stages of the motor act, that is, skill-focused attention.

Why did we not find that an external focus was better than an internal focus for less-skilled players as has been reported in several previous studies by Wulf and colleagues? As discussed above, one possibility is that our dual-task methodology introduced additional task demands that were not present in the instruction paradigm used by Wulf and colleagues and our less-skilled players could not perform under these additional demands. A second possibility is that the effects of attentional focus are different for baseball batting than for the sporting tasks that have been investigated in past research perhaps owing to the severe time constraints involved in hitting a baseball (Watts & Bahill, 1991). A third possibility is that we used less-skilled baseball players in the present study, whereas the previous studies by Wulf and colleagues used pure novices. In the future, we plan to further address this discrepancy by directly comparing dual-task and verbal instruction methodologies within a single study.

In summary, we would conclude that directing attention to any aspect of skill execution (e.g., either the movement of the limbs or the bat) will result in optimal performance for less-skilled baseball players. Additional support for this conclusion is given by our finding that batting performance in the two *skill-focused* conditions was better than in the control condition, although, as discussed above, the results from the control condition must be treated with caution. Consistent with the dominant theories of skill acquisition (e.g., Fitts & Posner, 1967), we propose that skill-focused attention is optimal for less-skilled players because attention to each of the stages of motor execution is necessary for successful execution in less-skilled players.

Conclusion

Results from the present study on baseball batting provided mixed support for the two dominant accounts of the role of attention in skilled performance. Whereas results from our highly skilled players appeared to be more consistent with the *internal* vs. *external* account of Wulf and colleagues, results from our less-skilled players appeared to be more consistent with the *skill-focused* vs. *environmental* account of Beilock, Gray, and colleagues. One of the main difficulties in comparing these two accounts is the major differences between the verbal instruction and dual-task methodologies for manipulating a performer's attention that have been used by these two groups of researchers. Future studies directly comparing these two methodologies are needed to resolve some of these discrepancies.

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Note

1. We also ran a follow-up study in which there were "catch trials" for all four attention conditions. In the catch trials (which occurred randomly and comprised 10% of the total number of trials), the ball changed color from white to gray during its simulated flight. Participants were instructed to say the word *color* when this occurred. The same 16 participants completed this follow-up study. If our batters were looking at their bat or hands during the skill-focus conditions we would expect them to miss saying *color* (because the change was very subtle) more often than for the environmental-focus conditions. This was not the case: There was no significant difference in the percentage of correct catch trial responses for the four conditions, suggesting that participants were looking at the ball for all conditions. Mean percentages of correct values for less-skilled players were as follows: skill/internal focus: 76.2 ($SE = 3.4$), skill/external focus: 74.3 ($SE = 3.1$), environmental/external focus: 79.2 ($SE = 3.5$), and environmental/irrelevant focus: 72.8 ($SE = 2.7$). Mean percentage correct values for highly skilled players were as follows: skill/internal focus: 83.7 ($SE = 3.2$), skill/external focus: 80.1 ($SE = 2.7$), environmental/external focus: 84.4 ($SE = 2.7$), and environmental/irrelevant focus: 81.2 ($SE = 1.9$).