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Hitting is Contagious: Experience and Action Induction

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In baseball, it is believed that "hitting is contagious," that is, probability of success increases if the previous few batters get a hit. Could this effect be partially explained by action induction—that is, the tendency to perform an action related to one that has just been observed? A simulation was used to investigate the effect of inducing stimuli on batting performance for more-experienced (ME) and less-experienced (LE) baseball players. Three types of inducing stimuli were compared with a no-induction condition: *action* (a simulated ball traveling from home plate into left, right, or center field), *outcome* (a ball resting in either left, right, or center field), and *verbal* (the word "left", "center", or "right"). For both ME and LE players, fewer pitchers were required for a successful hit in the *action* condition. For ME players, there was a significant relationship between the inducing stimulus direction and hit direction for both the action and outcome prompts. For LE players, the prompt only had a significant effect on batting performance in the action condition, and the magnitude of the effect was significantly smaller than for ME. The effect of the inducing stimulus decreased as the delay (i.e., no. of pitches between prompt and hit) increased, with the effect being eliminated after roughly 4 pitches for ME and 2 pitches for LE. It is proposed that the differences in the magnitude and time course of action induction as a function of experience occurred because ME have more well-developed perceptual-motor representations for directional hitting.

Keywords: baseball, mirror neurons, visual perception, motor control, induction

A commonly held belief in the sport of baseball is that "hitting is contagious" (Will, 1990). In other words, if the previous few batters are successful in hitting the ball and getting on base it will increase the probability that the current batter will also get a hit. Indeed Major League Baseball (MLB) statistics provides some support for this belief as batting averages are roughly 50%–70% points higher for a batter following hits by the previous two batters as compared to outs made by the previous two batters (Ross, 2004). It is likely that the effect is driven by multiple factors including pitcher ability (if the previous few batters are successful it is likely that the pitcher's current performance level is lower), batter motivation (there is more incentive for a batter to get a hit with runners on base because it is likely to result in a run being scored), pitcher pressure (the added pressure of having runners on base may lead to a decline in performance by the pitcher, e.g., Beilock & Carr, 2001; Gray, 2004), and strategy (it is well-known that pitchers throw different pitch types with runners on base, e.g., Williams & Underwood, 1970). The focus of the present study is another potential influence on this effect: action induction.

Observing an action performed by somebody else induces in an observer a tendency to perform an action that is somehow related (Katz, 1960). Examples of these types of induced actions, often called "ideomotor movements", include a person yawning when they observe someone else yawn and a vehicle passenger pressing an imaginary brake as the driver approaches an intersection. Ideomotor movements can occur both when the observer views the execution of the action (as in the yawning example) and when an observer views only the outcome of the action (as in the braking example). A theoretical basis for induced actions is provided by Prinz's (1997) "common coding" principle. Common coding suggests that actions are planned and controlled by their intended effects. As in earlier feedback-based control theories (see Powers, 1973), Prinz proposed that the governing nodes in motor control hierarchies are intended environmental changes that actions should create. In other words, the perception of an action outcome engages the same neural systems involved in the planning of a future action. This link between perception of action outcome and action execution is supported by physiological studies examining "mirror neurons" in the premotor cortex of monkeys (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996). These neurons are active during action execution (as one would expect from a neuron in the premotor cortex) but also when the monkey observes the same action being performed by an experimenter.

Could this type of induced action be involved in the "hitting is contagious" effect? There is some evidence that the answer is "yes". For instance, athletic performance is significantly improved if athletes view videos (just prior to competition) of themselves or somebody else successfully executing an action related to their sport (Leavitt, Young, & Connelly, 1989; Templin & Vernachhia, 1995). Of course, these performance improvements could also be due to many of the other factors described above (e.g., increased motivation or self-confidence). Nonetheless, in more controlled laboratory experiments, evidence also exists for an induced action

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effect in sensorimotor skill performance that might also occur in a baseball batting context.

Brass, Bekkering, and Prinz (2001) asked participants to perform a simple finger movement (either lifting or tapping), following observation of a compatible or incompatible finger movement. It was found that movement response times were faster when the inducing stimulus was compatible with the assigned action. Likewise, in a study by Castiello, Lusher, Mari, Edwards, and Humphreys (2002), participants observed a grasp action directed to an object and then had to either grasp the same or a different object, which became visible a fixed 3 s after the inducing stimulus. Time to peak velocity occurred earlier and peak grasp aperture was smaller for valid (i.e., when the observed object was the same size as the object to be reached) than invalid trials. The faster reach and more precise grasp indicated that observation of a matching action facilitated subsequent execution. Moreover, the more the observed action matches the action to be performed, the stronger the facilitation effects. For example, Brass et al. (2000) found a greatly reduced induction effect for finger movements when videos of fingers were replaced with moving dots and Castiello et al. (2002) reported that observation of a robot hand and arm that move to grasp the objects did not affect subsequent movements by participants in the same manner that observing an actual hand did.

In the aforementioned studies, it is important to note that the inducing stimuli and actions used were binary, for example, reach to large or small object, move finger up or down. Therefore, there was always a correct response that was either validly or invalidly cued by the inducing stimulus. However, in baseball (and for many other actions we perform) there is a wide range of actions that are considered to be a successful response outcome. For example, a batter is not required to hit the ball in a specific direction to be successful. Therefore, it seems reasonable to ask whether action induction occurs when the inducing stimulus is just an example of one of the possible outcomes the actor is trying to achieve? Research on mimicry provides some evidence that ideomotor behavior can occur when there is no particular response required from the participant. For example, Chartrand and Bargh (1999) demonstrated that we often unconsciously mimic the postures, mannerisms, and facial expressions when interacting with others, even though there is ostensibly no one "correct" posture or mannerism in which to engage.

A second important question concerns the relative timing of the observed and induced actions. In previous research with discrete motor actions there was always a fixed delay between observation of the inducing stimulus and the initiation of the action. Conversely, because a baseball batter is not always successful on the first pitch there can be a delay of several seconds (or even minutes) between the inducing stimulus (the previous batter) and action execution (hitting the ball). Can the representation activated by observation of an action outcome alter an action that is executed after a considerable delay? In other words, what is the time course of action-induction effects?

Finally, exploring action induction in a sporting context raises an interesting question in regard to sensorimotor skill expertise. Common coding theory suggests that as practice accumulates, links between perceived action outcomes and the processes that produce the outcome should strengthen because experts have more and more direct experience of the consequences of their actions (Prinz, 1997; Repp & Knoblich, 2004). In one of the first studies to address differences in the neural activity that underlies action observation in people with more or less motor experience with those actions, Calvo-Merino, Glaser, Grezes, Passingham, and Haggard (2005) used functional MRI (fMRI) to study brain activation patterns when individuals watched an action in which they were skilled, compared to one in which they were not skilled. Experts in classical ballet or Capoeira (a Brazilian art form that combines elements of dance and martial arts) watched videos of the two activities while their brains were being scanned. Brain activity when individuals watched their own dance style was compared to brain activity when they watched the other unfamiliar dance style (e.g., ballet dancers watching ballet vs. ballet dancers watching Capoeira). Greater activation was found when experts viewed the familiar versus the unfamiliar activity in a network of brain regions thought to support both the observation and production of action (e.g., bilateral activation in premotor cortex and intraparietal sulcus, right superior parietal lobe, and left posterior superior temporal sulcus; Rizzolatti, Fogassi, & Gallese, 2001). These findings suggest that experience performing particular actions alters the neural substrates called on to understand these actions.

To explore whether doing (as opposed to seeing) the actions was responsible for the effect, Calvo-Merino, Grezes, Glaser, Passingham, and Haggard (2006) examined brain activation in male and female ballet dancers. Each gender performs several moves not performed by the other gender. But because male and female ballet dancers train together, they have extensive experience seeing (although not doing) the other gender's moves. Calvo-Merino et al. (2006) found greater premotor, parietal, and cerebellar activity when dancers viewed moves from their own repertoire, compared to moves performed by the opposite gender. Having produced an action affected the way the dancers perceived the action, suggesting that the systems involved in action production subserve action perception as experience performing increases.

The goal of this study was to use a simulated baseball batting task (Gray, 2002a) to investigate action induction in baseball batters of different skill levels. Participants (college and recreational baseball players) viewed an inducing stimulus (a ball traveling to a particular location on the field, a stationary ball sitting in a particular location on the field, or a text message indicated in which location the ball landed) and then attempted to hit a simulated pitched ball. Three different prompt directions (left, center, and right) and a no-prompt condition were used. If participants missed the ball, they continued receiving pitches until the ball was contacted, therefore there were variable delays between the inducing stimulus and the action. On the basis of the previous research on ideomotor behavior and mirror neurons, we made the following predictions:

1. Batting performance would be significantly better when the batter viewed an inducing prompt (that was a successful hit) than when no prompt was presented.

2. When the ball was hit by the batter, its direction of travel would be significantly related to the direction of the prompt (i.e., more balls would be hit to left field following a left prompt than a right prompt).

3. On the basis of the previous work of Brass, Bekkering, and Prinz (2001), it was predicted that the magnitude of the induction effect (i.e., the difference between the prompt and no-prompt conditions) would be significantly greater when the prompt closely matched the action to be performed (ball traveling onto field) than when the prompt–action relationship was more abstract (verbal prompt).

4. The magnitude of the induction effects would be significantly greater for more-experienced batters than for less-experienced batters.

5. The magnitude of the induction effect would decrease as the time interval between the inducing stimulus and the ball being hit increased.

Experiment 1

Method

Participants. Twenty-four male baseball players completed the study. The 12 "more-experienced" batters played for a college baseball team affiliated with the National Junior College Athletic Association (NJCAA). The mean age of these participants was 20.0 ($SE = 0.3$) and the mean number of years of competitive playing experience was 10.0 ($SE = 0.3$). The 12 less-experienced batters were currently playing in competitive recreational leagues and had never played college baseball. The mean age of these participants was 22.1 ($SE = 1.0$), and the mean number of years of competitive playing experience was 5.9 ($SE = 0.8$). *T* tests revealed that the number of years of competitive playing experience was significantly greater for more-experienced players, $t(22) = 5.4$, $p < .001$, whereas there was no significant difference in age between the two groups, $t(22) = 1.9$, $p > .05$. All participants gave informed consent.

Apparatus. The baseball batting simulation used in this study has been used in several previous experiments (Gray, 2002a, 2002b, 2004; Castaneda & Gray, 2007; Gray, 2009a, 2009b; Gray, 2010; Gray, Beilock, & Carr, 2007; Scott & Gray, 2010). Participants swung a baseball bat at a simulated approaching baseball. The simulated ball was an offwhite sphere texture mapped with red laces. The image of the ball, a pitcher, and the playing field were projected on a 2.11 m (h) × 1.47 m (v) screen using a Proxima 6850 + LCD projector updated at a rate of 60 Hz. Batters stood beside a standard 0.45 m × 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 (Rawlings Big Stick Professional Model; 84 cm [33 in.]) was a sensor from a Fastrak (Polhemus) position tracker. A sensor was also mounted on the batter's lead foot (i.e., the one closest to the screen when they were in their batting stance). The x, y, z position of the end of the bat and the batter's foot were recorded at a rate of 120 Hz. The estimated static positional precision of our tracking system (<0.2 mm) was derived from the standard deviation of 50 samples with the receivers at a constant position. The dynamic precision of the system (<1 mm) was estimated by using the method described by Tresilian and Longergan (2002). Similar values were obtained for the x, y, and z coordinates.

A sensation of motion toward the batter was created by increasing the angular size of the ball. The angular size of the ball, pitcher, and other objects was based on the visual angle subtended by these objects from the batter's perspective. 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 that affected 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

$$z(t) = -1/2 * g * t^2, \tag{1}$$

where g is acceleration of gravity ($9.8 \mathrm{m/s}^{-2}$).

All pitches in this study crossed the plate within the batter's strike zone. The MLB definition of the strike zone (Triumph Books, 2004) was used to determine balls and strikes:

> The strike zone is that area over home plate the upper limit of which is a horizontal line at the midpoint between the top of the shoulders and the top of the uniform pants, and the lower level is a line at the top of the knees. (p. 55)

Pitches ranged in speed between 37 m/s (84 mph) and 40 m/s (89 mph) and had *underspin* (i.e., rotated from the ground to the sky as it approached the plate). The launch angle of the pitch varied between −1° to 1° to create different pitch crossing heights. All pitches traveled down the center of the plate.

Each trial began with a 10 s view of the playing field and the virtual pitcher. The simulated pitcher then executed a 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.

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 homeruns [(fair balls that traveled further than 107 m (350 ft)], an audio file of an announcer's home run call from an actual game was played. The duration between the completion of the feedback and the onset of the pitcher's delivery for the next trial was 5 s.

Procedure. Each batter first completed one practice block of 25 pitches to allow them to become accustomed to the batting simulation. There were no inducing stimuli in these practice trials. An experimental block ("at-bat") proceeded as follows. Batters were given the following instruction (both verbally and in text on a sheet of paper):

> You are about to have an at-bat in which the pitcher will continue to throw pitches until you successfully hit the ball. A successful hit is when you hit the ball beyond the infield and it lands anywhere in fair

> play. Ground balls that travel beyond the infield count as a hit. You will receive points for your performance and the batter with the largest total number of points in this study will receive a monetary prize of $25 at the end. Points will be assigned as follows: hit on 1st pitch in the at-bat = 5 points, hit on 2nd pitch in the at-bat = 4 points, hit on 3rd pitch in the at-bat = 3 points, hit on 4th pitch in the at-bat = 2 points, and hit on 5th pitch in the at-bat = 1 point. If you do not get a hit after 5 pitches you will be called "out" and a new at-bat will start. Prior to the first pitch in each at-bat being delivered you will see an image presented on the screen (either a ball flying onto the field, a ball sitting on the field, a word on the screen, or an empty field) that will last for 10 sec. Please keep looking at the screen for the entire 10 sec. You will be asked to complete a total of roughly 30 at-bats with short breaks in between.

These instructions were only given before the first at-bat in the study but batters could request them again at any point.

There were a total of 30 different experimental blocks (at-bats) corresponding to three repeats for each of the 10 prompt conditions described below. The order of prompts was counterbalanced across batters. There were 5-min rest breaks in between blocks to reduce fatigue effects. If a batter did not successfully hit the ball after the five pitches, the same block was repeated until a hit occurred. In no cases did batters require more than one repeat of a block to achieve a successful hit. As a result of this procedure, the number of pitches varied across conditions and batters. All prompts were 10 s in duration. The following are the four prompt types.

Action. Prompts in this condition consisted of the simulated ball traveling from home plate into the simulated field (as if it were hit by the participant). There were three possible prompts in this condition: ball traveling to left field, ball traveling to center field, and ball traveling to right field. In all cases the ball landed and stopped immediately 15.2 m (50 ft) from the simulated outfield fence.

Outcome. Prompts in this condition consisted of a static ball resting in the field. There were three possible prompts in this condition: left field, center field, and right field. The location of the ball in each condition was identical to the stopping point of the ball in the analogous action prompt conditions.

Verbal. Prompts in this condition consisted of words superimposed on the simulated playing field. There were three possible words: "left", "center", and "right". Words were white in color, and letters subtended 10° vertically.

None. In this condition batters viewed an empty playing field (with no simulated ball or prompt words).

Data analysis.

Number of pitches required to achieve a "hit". The first dependent variable of interest was the mean number of pitches required to achieve a hit. These data were analyzed by using a 2 × 4 mixed-factor analysis of variance (ANOVA), with experience (more experienced, less experienced) as the between-subjects factor and prompt type (action, outcome, verbal, and none) as the within-subject factor. Note that data were averaged across the three prompt directions for this analysis because it was found in pilot tests that prompt direction did not have a significant effect on this dependent variable. Each of the inducing prompt types (action, outcome, verbal) was compared with the no-prompt condition, using two-tailed *t* tests with Bonferroni correction for Type I error.

Azimuth angle. The second dependent variable of interest was the direction of ball travel for successful hits. Using the simulated ball's velocity vector before contact (vball), the bat's velocity vector before contact (vbat), and the calculated contact location, the velocity vector of the ball after contact (vball′) was estimated using the following equation:

$$\vec{\upsilon}\,ball' \approx \vec{\upsilon}\,ball_t + \vec{\upsilon}\,bat_n, \qquad (2)$$

In this equation vball$_t$ and vbat$_n$ are the components of the velocity vectors tangential and normal to plane of collision respectively (Adair, 1990). Azimuth angle was then derived by calculating the angle between vball and vball′. This angle could vary between 0° (a ball hit into the left field dugout) and 180° (a ball hit into the right field dugout). For the dimensions of the simulated field, any angle between 56° and 124 ° corresponded to a fair ball. The left field, right field, and center field prompts in the action and outcome conditions had azimuth angles of 73°, 90°, and 107°, respectively.

Mean azimuth angle was analyzed using a 2 × 3 × 3 mixed-factor ANOVA with experience (more experienced, less experienced) as the between-subjects factor and prompt type (action, outcome, and verbal) and prompt location (left, center, and right) as within-subject factors. Each of the prompt directions (left, right, and center) was compared with the no-prompt condition, using two-tailed *t* tests with a Bonferroni correction for a Type I error.

Swing kinematics. Two kinematic dependent variables were also analyzed: swing onset time and swing velocity. These two particular variables were chosen because previous research has shown that they are two of the primary aspects of the swing that are adjusted by the batter from pitch to pitch (Scott & Gray, 2010). Swing onset time was defined as the time elapsed between the pitcher releasing the virtual ball and downward motion of the bat occurring. The criterion for the onset of downward bat motion was identical to that used in previous simulated hitting studies (e.g., Gray, 2002a): five consecutive height samples that were lower than the previous sample. Swing velocity was defined as the maximum velocity of the end of that bat that occurred between swing onset and the bat crossing the front of the plate (Gray, 2002a). These variables were analyzed using two separate 2 × 3 × 3 mixed-factor ANOVAs with experience (more experienced, less experienced) as the between-subjects factor and prompt type (action, outcome, and verbal) and prompt location (left, center, and right) as within-subject factors.

Cohen's *f* and *d* statistics were used as an unbiased estimate of effect size.

Results and Discussion

Number of pitches required to achieve a hit. Figure 1 shows the mean number of pitches required to achieve a hit for the four prompt types (action, outcome, verbal, and none). The ANOVA performed on these data revealed a significant main effect of experience, $F(1, 22) = 82.3$, $p < .001$, $f = 1.1$, as more-experienced batters required fewer pitches to achieve a hit. There was also a significant main effect of prompt type, $F(3, 66) = 13.7$, $p < .001$, $f = 0.51$. The Experience × Prompt Type interaction was not significant ($f = 0.4$). Post hoc comparisons revealed that for more-experienced batters the number of pitches required to achieve a hit was significantly lower for the action prompt than for no prompt, $t(11) = 4.9$, $p < .001$, $d = 2.2$, and was significantly lower for the outcome prompt than for no prompt, $t(11) = 2.9$, $p <$

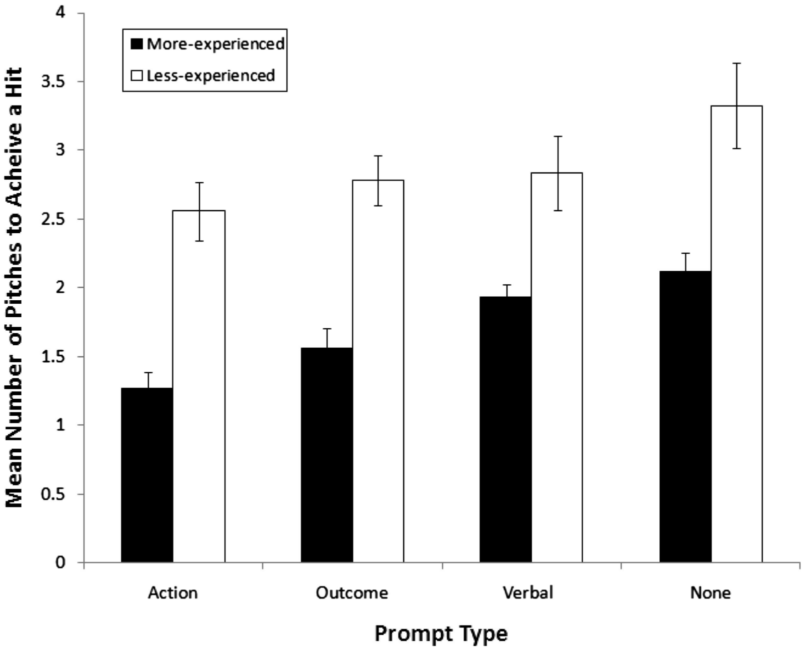

Figure 1. The mean number of pitches required to achieve a hit in Experiment 1. Error bars are standard errors. See text for details.

.01, $d = 1.4$. For less-experienced batters, the number of pitches required to achieve a hit was significantly lower for the action prompt than for no prompt, $t(11) = 3.4$, $p < .01$, $d = 0.95$. None of the other post hoc comparisons was significant, and effect sizes were all <0.5.

Azimuth angle. Figure 2 shows the mean azimuth angles for simulated balls hit by the more-experienced (A) and less-experienced (B) batters in our study. The horizontal lines in this figure show the mean azimuth angles for hits in the no-prompt condition. These data are only for hits that occurred in the first pitch after the inducing stimulus (data for other pitches are examined below). As a reminder, azimuth angles could vary between 0° (a ball hit into the left field dugout) and 180° (a ball hit into the right field dugout). It is clear from this figure that, overall, the prompt direction influenced the direction in which the ball was hit by the batters. Consistent with an action induction effect, balls hit following a left prompt had an azimuth angle closer to the left-field line (56°) than balls hit following the right prompt. The ANOVA performed on these data revealed a significant three-way interaction of 3 (prompt type: action, outcome, verbal) × 2 (experience: more-experienced, less-experienced) × 2 (prompt direction: left, center, right), $F(4, 88) = 5.72$, $p < .001$, $f = 0.31$. To understand this interaction, we next looked at the relation between experience and prompt direction for the three different prompt types separately.

For the action prompt, a 2 (more experienced, less experienced) × 3 (prompt direction: left, center, right) ANOVA on azimuth angle revealed a significant main effect of prompt direction, $F(2, 22) = 14.5$, $p < .001$, $f = 0.52$, and a significant Experience × Prompt Direction interaction, $F(2, 22) = 8.6$, $p < .01$, $f = 0.61$. The main effect of experience was not significant ($f = 0.22$). From Figure 2 it is clear that this interaction occurred because the effect of prompt direction was substantially larger for more-experienced batters than for less-experienced batters in the action condition. For more-experienced batters, the mean azimuth angle in the no-prompt condition was 87.3° ($SE = 1.3$), a value that was significantly higher than the mean angle in the left prompt condition, $t(11) = 2.9$, $p < .01$, $d = 1.1$; significantly lower than the mean angle in the right prompt condition, $t(11) = -3.0$, $p < .01$, $d = 1.2$; and not significantly different than the mean angle in the center prompt condition ($p > .5$, $d = 0.03$). For less-experienced batters, the mean azimuth angle in the no-prompt condition was 91.6° ($SE = 1.7$). This value was not significantly different than the mean angle in the left, right and center prompt conditions (all ps $> .05$). Note, however, that medium effect sizes were found for the left ($d = 0.4$) and right ($d = 0.5$) prompt conditions.

For the outcome prompt, the 2 × 3 ANOVA on azimuth angle revealed a significant main effect of prompt direction, $F(2, 22) = 4.5$, $p < .05$, $f = 0.38$, and a significant Experience × Prompt Direction interaction, $F(2, 22) = 3.7$, $p < .05$, $f = 0.27$. The main effect of experience was not significant ($f = 0.15$). From Figure 2, it is clear that this interaction occurred because the effect of prompt direction was substantially larger for more-experienced batters than for less-experienced batters. For more-experienced batters, the mean azimuth angle in the no-prompt condition was significantly higher than the mean angle in the right prompt condition, $t(11) = 3.2$, $p < .01$, $d = 1.3$, but it was not significantly different than the mean angle in either the left prompt or center prompt condition ($p > .1$ for both, $d = 0.3$ and 0.4, respectively). For less-experienced batters there were no significant differences between the mean azimuth angles in the left, center, or right prompt conditions and the mean azimuth angle in the no-prompt condition (all ps $> .25$, all ds < 0.3).

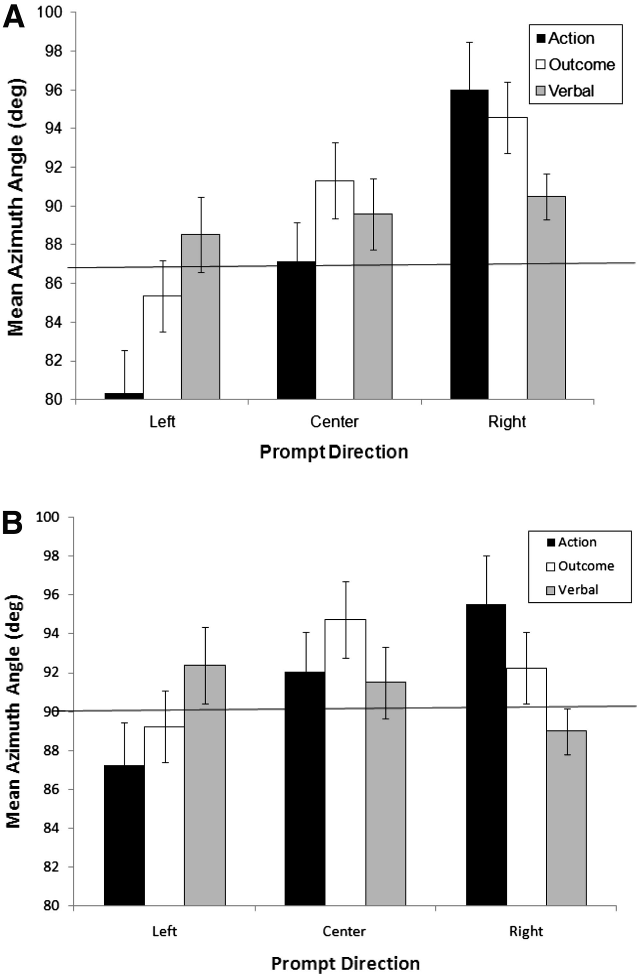

Figure 2. Mean azimuth angles for simulated balls hit in the three inducing conditions by the more-experienced (A) and less-experienced (B) batters. Horizontal lines plot the mean azimuth angle for hits in the no-prompt conditions. Error bars are standard errors.

For the verbal prompt, the 2 × 3 ANOVA on azimuth angle revealed no significant main effects or a significant interaction (all *f*s < 0.3). For both more-experienced and less-experienced batters there were no significant differences between the mean azimuth angles in the left, center, or right prompt conditions and the mean azimuth angle in the no-prompt condition.

Effect of number of pitches. Figure 3 plots the mean difference between the azimuth angles for the left prompt and the right prompt (i.e., the magnitude of the action induction effect) as a function of pitch number for which the simulated ball was hit. To understand these data, we examined the relation between experience and pitch number for the three different prompt types separately.

For the action prompt, a 2 (more experienced, less-experienced) × 5 (pitch No. 1–5) ANOVA on the mean difference between the azimuth angles revealed a significant main effect of pitch number, *F*(4, 44) = 51.1, *p* < .001, *f* = 0.92, and a significant Experience × Pitch Number interaction, *F*(4, 44) = 6.3, *p* < .01, *f* = 0.57. It is clear from Figure 3 that the effect of pitch number (i.e., the slope) was much larger for more-experienced batters than for less-experienced batters. Note, however, that because we could not compare slopes statistically the difference in decay rates could also be explained by the fact that more-experienced batters had a larger initial magnitude of action induction. The main effect of experience was not significant (*f* = 0.21). Pairwise comparisons (corrected for Type I error, using a Bonferroni correction) revealed that for more-experienced batters the difference between the left and right prompts was significantly different from 0.0 for pitch No. 1, *t*(11) = 8.1, *p* < .001; No. 2, *t*(11) = 5.5, *p* < .001; No. 3, *t*(11) = 3.1, *p* < .01; and No. 4, *t*(11) = 2.8, *p* < .01. This difference was not significant for pitch No. 5. Conversely, for less-experienced batters the difference between the left and right prompts was only significantly different

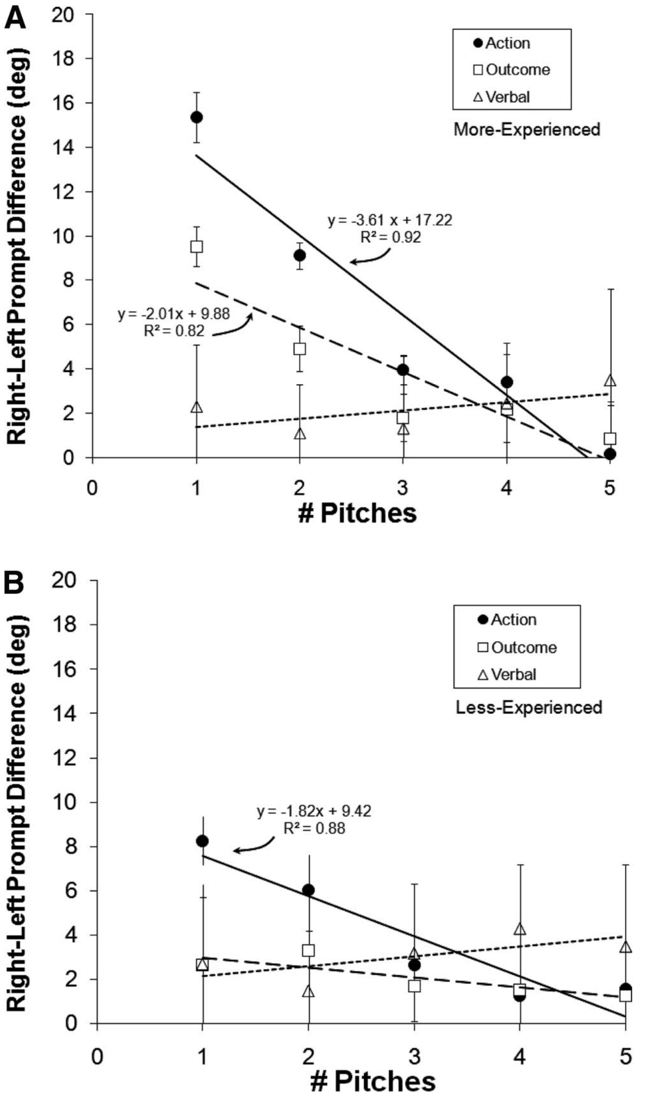

Figure 3. Mean difference between the azimuth angles for the “left” prompt and the “right” prompt (i.e., the magnitude of the action induction effect) as a function of the pitch number for which the simulated ball was hit. A: more-experienced batters, B: less-experienced batters. Error bars are standard errors.

from 0.0 for pitch No. 1, $t(11) = 4.6, p < .001$. This difference was not significantly different for pitch Nos. 2–5 (all $ps > .01$).

For the outcome prompt, a 2 (more experienced, less experienced) × 5 (pitch No. 1–5) ANOVA on the mean difference between the azimuth angles revealed a significant main effect of pitch number, $F(4, 44) = 9.4, p < .001, f = 0.75$. The main effect of experience and Experience × Pitch Number interaction were not significant ($f < 0.3$). Pairwise comparisons revealed that for more-experienced batters the difference between the left and right prompts was significantly different from 0.0 for pitch No. 1, $t(11) = 4.1, p < .05$, and No. 2, $t(11) = 3.0, p < .01$. None of the other pairwise comparisons were significant.

For the verbal prompt, a 2 (more experienced, less experienced) × 5 (pitch No. 1–5) ANOVA on the mean difference between the azimuth angles revealed no significant effects (all $ps > .5$).

Swing kinematics. Mean swing onset times for the different prompt conditions are shown in Figure 4. The horizontal lines in this figure show the mean swing onset times for the no-prompt condition. The ANOVA performed on these data revealed only a significant main effect of experience, $F(1, 44) = 22.7, p < .01, f = 0.55$, as the swing onset times were significantly shorter for more-experienced batters. None of the other main effects or interactions were significant (all $fs < 0.3$).

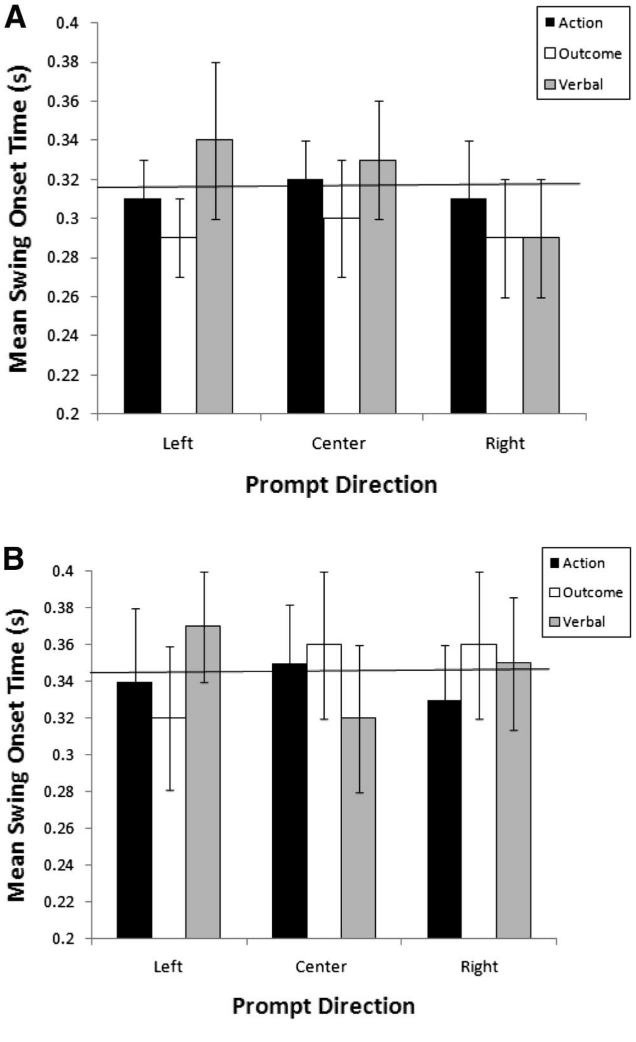

Figure 4. Mean swing onset times in the three inducing conditions for the more-experienced (A) and less-experienced (B) batters. Horizontal lines plot the mean azimuth angle for hits in the no-prompt conditions. Error bars are standard errors.

Mean bat velocities for the different prompt conditions are shown in Figure 5. The ANOVA performed on these data revealed only a significant main effect of experience, $F(1, 44) = 68.9, p < .001, f = 1.4$, as bat velocities were significantly higher for more-experienced batters. None of the other main effects or interactions were significant (all $fs < 0.3$).

In Experiment 1, we found a reliable effect of action observation on hitting performance in a baseball batting simulator. In particular, we found that the angle the ball was hit was shifted in the direction of the inducing stimulus. We also found that this effect was stronger for more-experienced batters. Although these effects suggest that an induction effect does indeed occur in baseball, it is important to note that there is another interpretation for the Experiment 1 results. Namely, perhaps participants interpreted the prompt as an instruction to attempt to hit the ball in the particular direction of the prompt and more experienced batters were just better at following these instructions than less experienced batters. Although this interpretation does not seem likely given that we found our induction effects to be moderated by the type of prompt (e.g., verbal vs. outcome vs. action), which should all presumably yield similar effects if participants were just doing what they were instructed to do, we ran a second experiment with just experienced batters designed to specifically address this instruction issue.

Experiment 2

Purpose

The goal of Experiment 2 was to investigate to what extent the results from Experiment 1 were due to an instruction effect (i.e., participants interpreted the prompt as an instruction to attempt to hit the ball in a particular direction). To address the question, batters in Experiment 2 were explicitly instructed to attempt to hit the ball directly over second base (i.e., to center field) on every trial.

Method

Participants. Ten experienced batters that played for a college baseball team affiliated with the National Junior College Athletic Association (NJCAA) completed Experiment 2. None of these batters participated in Experiment 1. The mean age of these participants was 19.6 ($SE = 0.5$) and the mean number of years of competitive playing experience was 9.2 ($SE = 0.4$).

Apparatus & procedure. The apparatus and procedure was identical to that described for Experiment 1 except for the following. In Experiment 2, only the three action prompts (left, center, right) and the no prompt were used. Prior to each block batters were instructed to “always try and hit the ball directly over 2nd base”. They were further instructed that they would receive 100 points for each hit in which the ball traveled over the second base bag and that the batter with the most points at the end of the study would receive a monetary prize of $25 at the end of the study.

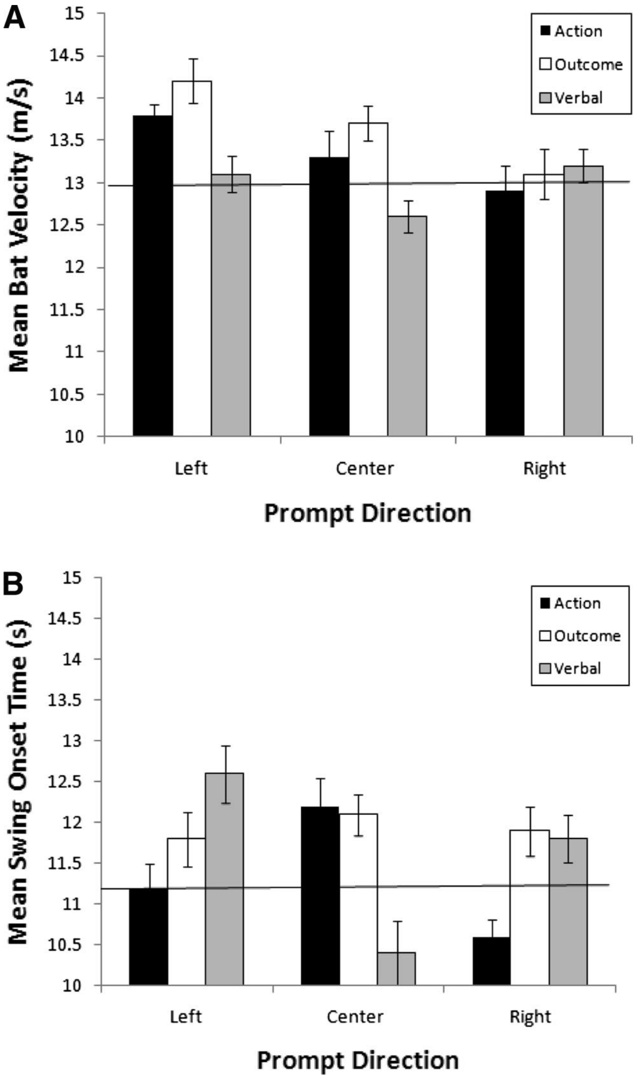

Figure 5. Mean bat velocity in the three inducing conditions for the more-experienced (A) and less-experienced (B) batters. Horizontal lines plot the mean azimuth angle for hits in the no-prompt conditions. Error bars are standard errors.

Data analysis. Mean number of pitches to achieve a hit and mean azimuth angle were analyzed by using separate one-way ANOVAs with prompt type (left, center, right, and none) as a within-subject factor. Each of the prompt directions (left, right center, and none) was compared with the no-prompt condition, using two-tailed *t* tests with a Bonferroni correction for Type I error.

Results and Discussion

Figure 6 shows the mean number of pitches required to achieve a hit in the four prompt conditions. The one-way ANOVA performed on these data revealed a significant effect of prompt type, $F(3, 27) = 6.0$, $p < .01$, $f = 0.43$. Consistent with results of Experiment 1, paired *t* tests (corrected for Type I error, using the Bonferroni method) revealed the number of pitches required to achieve a hit was significantly lower for each of the Action prompts (left, right, center) than for the no-prompt condition. Results of *t* tests were as follows: left, $t(9) = 3.5$, $p < .01$, $d = 1.5$; center, $t(9) = 2.7$, $p < .01$, $d = 1.1$; right, $t(9) = 3.7$, $p < .01$, $d = 1.8$.

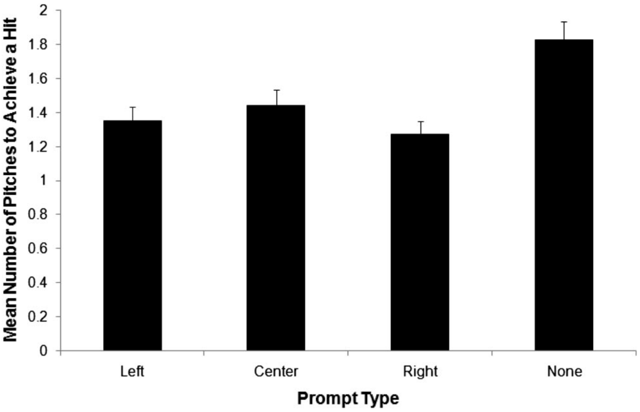

Figure 6. The mean number of pitches required to achieve a hit in Experiment 2. Error bars are standard errors.

Figure 7 shows the mean azimuth angle for balls that were successfully hit by the batter on the first pitch after the prompt. The one-way ANOVA performed on these data revealed a significant effect of prompt type, $F(3, 27) = 8.04$, $p < .001$, $f = 0.49$. Consistent with the results of Experiment 1, a paired *t* test revealed that the azimuth angle for the left prompt was significantly less than the angle in the right condition, $t(9) = 4.4$, $p < .01$, $d = 1.4$.

The pattern of results for both dependent variables is highly similar to the results for comparable conditions with more-experienced batters in Experiment 1, suggesting that the induction effects were not primarily due to an instruction effect. In other words, even when batters were instructed to hit the ball to a particular location, the prompt impacted performance.

General Discussion

A commonly held belief by players and coaches in baseball and other team sports is that if one or a few players on a team are

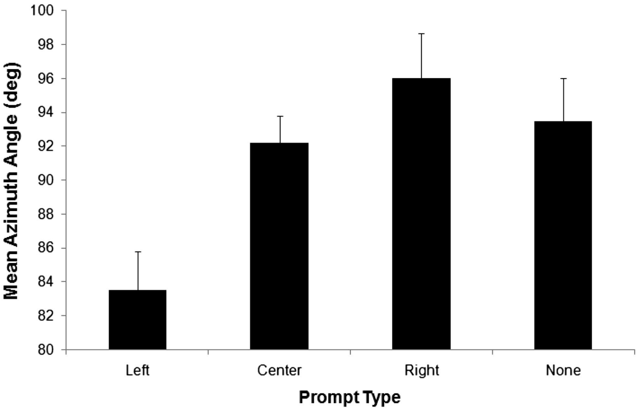

Figure 7. Mean azimuth angles for simulated balls hit in the three inducing conditions and the no-prompt condition in Experiment 2. Error bars are standard errors.

performing at a high level it will cause other players to improve their performance: "*Hitting is contagious*. One guy starts hitting well, the other guys are gonna catch on" (Tommy Lasorda, Los Angeles Dodgers); "Absolutely, hitting is contagious. You get a bunch of these guys hitting, hopefully the guys that aren't hitting right now will catch on fire" (Charlie Puleo, New York Mets). This effect is also believed to occur for poor performance as evidenced by the "comedy of errors" often seen in sports (i.e., the tendency for a team to string a series of bad plays together). The goal of this study was to investigate whether action induction (Katz, 1960) can provide a possible theoretical basis for these performance effects. Answering this question required extending previous research on action induction into a new direction that involves a complex, nonbinary motor action and participants of different skill levels.

On the basis of this previous anecdotal evidence and the experimental findings on action induction, we predicted the stimulus viewed just prior to attempting to hit a baseball would influence both hitting success (Hypothesis 1) and, if the ball was hit, the direction it traveled (Hypothesis 2). The results of this study provide strong evidence in support of both these predictions. The number of pitches required to achieve a hit was significantly lower following the action and outcome inducing stimulus for more-experienced batters and significantly lower following the action prompt for less-experienced batters. In other words, batters performed the hitting task more successfully when they viewed a successful outcome: It took roughly one less pitch to get a hit. Although this effect may seem small on the surface, it could make a substantial difference in a real baseball at-bat. Unlike in the presentation simulation, in real baseball there is a much wider range in pitch trajectory and pitch type so that "when facing a good pitcher a batter may only see *one good pitch to hit* during an at-bat" (Williams & Underwood, 1970, p. 32).

Consistent with Hypothesis 2, we found that the angle the ball was hit was shifted in the direction of the inducing stimulus. For example, if the inducing stimulus was a ball traveling to left field, the location the simulated ball was hit was more to the left (as compared to either no inducing stimulus or an inducing stimulus showing a ball traveling to center field). The magnitude of this effect could be quite large: For more-experienced baseball players the mean shift in ball location was roughly 8°, a value that equates to roughly 1/7 of a typical baseball field. Note that this finding is different than previous studies in which binary actions were used and the inducing stimulus was used to prime either the valid or invalid action for the next trial (e.g., Brass et al., 2001; Castiello et al., 2002). In this study, there was no incentive for participants to perform the particular action observed in the inducing stimulus—their only goal was to hit the ball into fair play.

As shown in Experiment 2, the effects of the inducing stimuli on hitting performance were significant even when batter's attempted to hit the ball in a particular direction (over second base) indicating that the results of Experiment 1 cannot be primarily explained as instruction effect (i.e., interpreting the prompt as instruction to hit the ball in a particular direction). In fact, the mean difference in azimuth angle for hits in the left and right prompt conditions in Experiment 2 (13.5°) was similar in magnitude to the difference found in the comparable condition of Experiment 1 (i.e., action prompt for more-experienced players: 15.1°). This finding suggests that, in this context, the motor action induced by the prompt is highly resistant to competing instructions.

Similar to previous studies (e.g., Brass et al., 2000) and consistent with Hypothesis 3, the induction effects found in the present study depended on the nature of the inducing stimulus. For all batters, induction effects were larger when they observed the ball traveling from home plate and into the field (the action prompt) than when they observed the ball resting in the field (the outcome prompt). This difference is perhaps not surprising given that there is typically only one motor action (hitting) that would result in the perceptual information observed in the action prompt (a ball traveling from the batter's waist level) whereas there are multiple actions that could lead to the observation of a ball sitting in the field (hitting, throwing, ball thrown by another player, etc.). For all batters, there was no significant induction effect for the verbal prompt. On the surface this may seem somewhat surprising given that athletes frequently develop associations between particular actions and verbal stimuli (i.e., instructions from their coach). However, in the sport of baseball, instructions about hitting during the game are usually given with hand signals from the third-base coach, players are expected to know where to hit the ball in a given situation and are not explicitly instructed (as discussed in more detail below), or both.

Consistent with Hypothesis 4, the effect of action induction on hitting performance also clearly depended on the batter's level of experience. For more-experienced batters in our study the induction effect in the action condition was significantly larger in magnitude (by 4.2° on average) as compared to less-experienced batters. Furthermore, for more-experienced batters we found a significant induction effect in the outcome condition (for both the number of pitches required to get a hit and the hit direction) while there were no significant effects for less-experienced batters in this condition. Why do more-experienced batters show a larger induction effect than less-experienced players? We would argue that this occurred because more-experienced batters have more well-developed sensorimotor representations for directional hitting.

In elite levels of baseball, batters are often required to attempt to hit the ball in a particular direction. For example, with a runner on second base and less than two outs, a batter's goal may be to attempt to hit the ball to right field (even if it results in an out) so that the base runner can move to third base and be driven by a sacrifice fly hit by the next batter. This skill, called "situational hitting" is one of the most difficult for a player to develop (Williams & Underwood, 1970). It requires not only making contact with the ball (which is difficult enough as it is) but also making contact with bat and hands moving in a particular direction, an action that requires extensive practice to master (McIntyre & Pfautsch, 1982). Therefore, it would be expected that (due to differences in the amount of practice) more-experienced batters have more developed and robust perceptual-motor representations for this task than less-experienced batters, that is, there is a stronger link between the desired observable outcome (e.g., ball traveling to right field) and the motor action required to achieve that outcome.

Because these links between actions and their observable outcomes are more developed, the actions of more-experienced batters are more reactive to inducing stimuli as compared to less-experienced players: Induction effects for more-experienced batters are greater in magnitude, decay at a slower rate and can be induced by both action and outcome stimuli. In other words, because more-experienced batters have a tighter link between action and outcome, their behavior can be altered more easily by environmental cues. Admittedly, this finding is somewhat surprising given that it has frequently between proposed that one characteristic of expertise in skilled performance is the production of highly consistent, low-variability movements that are relatively insensitive to extraneous environmental cues (e.g., Gray, 2004). Nonetheless, to the extent that perceiving an action outcome automatically potentiates a motor plan to enact the observed effect, and the more so the more experience one has linking actions and outcomes, more-experienced batters baseball players may be more influenced by what they observe than less-experienced players. This may also make more experienced players more predictable in their behavior, which could be a disadvantage in sports. For example, a pitcher could predict the motor plan of the hitter for the upcoming pitch based on the environmental cues (e.g., the pitch count or pitch history) and throw a pitch that makes this action difficult to execute. See Gray (2002b) for data and a model consistent with this prediction.

Consistent with Hypothesis 5, as the delay between the inducing stimulus and action execution increased the magnitude of the induction effect significantly decreased. The effect of the inducing stimulus on hit direction was effectively eliminated after four pitches for more-experienced players and two pitches for less-experienced players. In terms of time, these values equate to roughly 80 s and 40 s. These values are much larger than one might expect from research on mirror neurons (e.g., Gallese et al., 1996). It will be interesting for future research to explore the link between the decay in the behavioral measures like those observed in this study and decay in the activation of the brain areas involved in action induction.

The findings of this study have important theoretical implications for research on action induction and common coding. Unlike the simple movements investigated in most previous action induction research, a baseball swing is a highly complex motor action that involves several different muscle groups (including the lower extremities, trunk, and upper extremity) and has multiple phases of motor activation (Gray, 2002a; Shaffer, Jobe, Pink, & Perry, 1993; Welch, Banks, Cook, & Draovitch, 1995). Therefore, this study provides behavioral evidence that an inducing stimulus can activate a large network of motor units (instead of just a single muscle or muscle group).

The results of this study also have some important practical implications for baseball. First, because it was found that the effects of the inducing stimuli (both in terms of number of pitches to achieve a hit and hit direction) were larger for the action prompt than for the verbal prompt, directional hitting performance should be better if a coach showed a batter a video of their goal prior to hitting (e.g., a ball going to left field presented on an iPad) as compared to the current method of giving the batter a verbal instruction or hand signals. Second, the decay results in this study suggest that a batter should take less time to get up to bat when the previous batter is successful and more time to get to bat when the previous batter is unsuccessful.

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