Research Quarterly for Exercise and Sport
©2001 by the American Alliance for Health,
Physical Education, Recreation and Dance
Vol. 72, No. 1, pp. 22–31

Perceptual Decision Making for Baseball Pitch Recognition: Using P300 Latency and Amplitude to Index Attentional Processing

Steven J. Radlo, Christopher M. Janelle, Douglas A. Barba, and Shane G. Frehlich

This study was designed to examine the perceptual and attentional processes associated with the effects of administering a cost-benefit precuing paradigm to intermediate and advance-level baseball batters. Psychophysiological and performance data obtained from 10 advanced and 10 intermediate-level players were compared. A total of 400 pitches (200 fastballs, 200 curveballs) was randomly presented via a large projection screen, and participants pressed one of two buttons to indicate the type of pitch thrown. Verbal precues were given for 300 of the pitches. Of those, 75% were valid, and 25% were invalid. Electroencephalographic data collected from the P_z location was used to assess the latency and amplitude of P300. Analysis of variance (Skill Level x Precue x Pitch) for P300 and reaction time (RT) indicated that intermediate batters produced shorter P300 latencies, larger P300 amplitudes, longer RTs, and less correct responses than the advanced batters; the effects were more pronounced for the curveballs. These results suggest that intermediate batters are less efficient in their perceptual decision-making processes due to greater limitations in attentional capacity when compared with advanced batters.

Key words: event-related potentials, cost-benefit precuing

Hitting a baseball effectively can be a difficult perceptual-motor task. Being able to perform the physical requirements is only one aspect leading to successful ball contact. Batters must also have the ability to visually detect, early in the ball's flight, the rotation of the seams, the ball's trajectory, and the speed to determine the type of pitch thrown. Given that a fastball thrown 145 kph (90 mph) will reach home plate in approximately 375 ms, batters must complete their perceptual decision-making processes in about 150 ms, about the time it takes to blink an eye. On the other hand, a relatively slower pitch, such as a curveball, is typically thrown between 110–120 kph (70–75 mph) and allows the batter slightly more time to process the pitch. Consequently, misjudging the speed of a pitched ball by just 2 ms will likely result in a foul ball (Adair, 1994). Thus, such changes in the ball's speed can have an effect on the time allocated toward such perceptual processes as stimulus identification, pattern recognition, and memory template matching.

Recent studies in baseball and other sports requiring similar perceptual decision-making demands have supported the idea that when players use advanced cues extracted from their sporting environment, faster decision-making occurs (Bahill & LaRitz, 1984; Bard & Fleury, 1981; Hyllegard, 1991; McPherson & French, 1991; Ripoll, 1988; Singer et al., 1998; Williams & Davids, 1998; see also Abernethy, 1993 for a review). For instance, using visual search equipment, Goulet, Bard, and Fleury (1989) observed that expert tennis players made numerous fixations on the arm and racquet to determine the outcome of the

Submitted: September 21, 1998
Accepted: October 6, 2000

Steven J. Radlo is with the Department of Physical Education at Western Illinois University. Christopher M. Janelle is with the Department of Exercise and Sport Sciences at the University of Florida. Douglas A. Barba is with the Department of Exercise and Nutritional Sciences at San Diego State University. Shane G. Frehlich is with the Department of Exercise Science and Sport Studies at the State University of New York–Cortland.

tennis serve, whereas novices focused primarily on the tennis ball. Furthermore, in a study of baseball batters, Shank and Haywood (1987) showed that high-level players looked primarily to the area of the release point to predict pitch location. Beginners varied their fixations between the pitcher's head and the release point. Going further, Hyllegard (1991) demonstrated that batters used visual information provided by the seams of a pitched baseball when determining what type of pitch was thrown. Three types of baseballs were used: one was painted with white acrylic paint to make the ball appear to have no seams, a second ball was painted red to enhance the seams, and the third was a regular-seam, nonmodified baseball. Results revealed that baseball players could discriminate with more accuracy a pitch thrown with the enhanced-seam ball (85%) versus the regular-seam baseball (81%) and the no-seam baseball (74%). Therefore, the earlier a batter can visually detect the most pertinent information (e.g., seams of the baseball) and decide on the nature of the pitch, the more likely a correct response will be initiated.

Aside from visual search techniques, researchers have made attempts to investigate the mental actions of baseball batters by measuring their responses to a certain pitch (Bahill & LaRitz, 1984; Burroughs, 1984; Hanson, 1991; Hyllegard, 1991). Typically, batters would press a button or verbally report what they had seen to indicate their decision. It is clear these types of measurements may allow for introspection and are not sensitive to immediate changes that occur from the time the pitcher begins the wind-up to the time the batter decides to swing.

An experimental procedure that samples brain wave patterns during the perceptual decision-making period may enhance previous findings and provide a more direct and definitive index of information processing. Specifically, by averaging a batter's electroencephalographic (EEG) signals according to a time-locked stimulus event (presentation of the ball at the pitcher's release point), event-related potentials (ERPs) can be derived. Collecting ERP data can be a powerful technique, because it allows for the observation of mental changes *during* an event—not merely *before* or *after* the event.

ERPs are extracted from the ongoing EEG recording and have been described as transient voltage fluctuations generated in neural tissue immediately before, during, and after the occurrence of a stimulus event (Meyer, Osman, Irwin, & Yantis, 1988). Identifying characteristic peaks and troughs and measuring their latency and amplitude from the averaged waveform may better help to index stages or critical periods of information processing. A high degree of temporal resolution allows ERPs to represent a "window" on timing and organizing conscious and unconscious sensory, cognitive, and affective mentation of the brain (Zani & Rossi, 1991).

An ERP "peak," or component, that has received much attention in psychology research is P300 (a wave of positive in voltage that occurs approximately 300 ms after stimulus onset). Some researchers have called this component "P3," because the waveform is usually the third positive deflection in series and has occurred anywhere from 300–1,000 ms after stimulus presentation. Two key features of P300 have emerged from studies that relate this component with a specific cognitive processing stage or function.

The first feature is the latency of the P300. Many lines of research show that the latency onset of P300 is related to the time needed to fully evaluate a stimulus and is mainly independent of response selection processes (Campbell, Courchesne, Picton, & Squires, 1979; Kutas, McCarthy, & Donchin, 1977; McCarthy & Donchin, 1981; Ritter, Simson, Vaughan, & Friedman, 1979; Verleger, 1997). Thus, the presence of the P300 marks the time needed for such processes as stimulus discrimination, pattern recognition, classification, and memory template matching to occur. The second feature of the P300 is its amplitude. Factors such as subjective probability, stimulus discriminability, task demands, and stimulus meaning have had independent and additive contributions to the overall P300 amplitude. The contribution of these two variables on P300 amplitude, however, relies considerably on the proportion of stimulus information successfully transmitted (for comprehensive reviews, see Johnson, 1986, and Pritchard, 1981). Considerable evidence has also shown a close relationship between P300 amplitude and limited-capacity perceptual mechanisms (Donchin & Cohen, 1967; Hoffman, Simons, & Houck, 1983; Israel, Chesney, Wickens, & Donchin, 1980; Squires, Donchin, Squires, & Grossberg, 1977). Specifically, a task performed in a state of automaticity will produce a smaller P300 than a comparable task performed in a "nonautomated" mode. Thus, P300 amplitude could be used to identify the degree to which a task can be performed with or without attention.

With the potential to measure ERPs in a dynamic visual situation (Melnikov & Singer, 1998), the possibility of differentiating the visual and cognitive processes of elite athletes in their stimulus-relevant domain appears fruitful. For instance, sport researchers believe one of the reasons high-level athletes can attend to and process the most relevant information within a highly dynamical sport situation is that they have the ability to allocate a sufficient amount of attention to the most pertinent information and have enough "attentional reserve" to allocate to secondary perceptual information or for early response preparation processes (Abernethy, 1993). Beginners, on the other hand, need to allocate most if not all their attentional resources to the task at hand. For instance, Castiello and Ùmilta (1992) observed that expert volleyball players developed a quicker reorientation of attention to visual targets as opposed to inexperienced players. They attributed this enhanced attentional flexibility to the expert volleyball players' extensive practice in their sport, whereby quickly disengaging, moving, and engaging attention from one position to another is important. Thus, an attentional capacity theory of information processing can be tested in sport using different skill levels of athletes and by measuring their P300 amplitude changes to various sport-related action sequences that require a fast decision and immediate response.

One way to investigate an athlete's attentional capacity limitations is to correctly or incorrectly offer advance information about the nature of the upcoming stimulus presentation (Nougier & Rossi, 1999). This type of anticipatory strategy can be used to mimic a batter's mental preparatory state during the moments before a pitched ball. Known more commonly as Posner's (1980) cost-benefit paradigm, this experimental procedure suggests that if a person is precued in advance of the imperative stimulus and the information conveyed by the precue assists in the correct response, then faster reaction times (RTs) will be produced with greater accuracy. If, on the other hand, the advance cue incorrectly informs the participant, slower RTs and less accuracy will likely result.

Thus, the purpose of this study was to present sport-specific information to advanced and intermediate batters using a cost-benefit protocol to examine their perceptual and decision-making skills. RT, accuracy, P300 latency, and P300 amplitude were collected to investigate potential differences between the advanced and intermediate batters. It was hypothesized that because of the familiarity advanced batters have in recognizing the difference between a curve and a fastball, they would devote less attention to perceptual processes and afford more effort to decision-making processes (i.e., adjusting to an invalid precue). On the other hand, intermediate batters would allot more effortful processing to perceptual processes and less to decision-making processes, thus being affected more by an invalid precue. Advanced batters would produce faster RTs, greater accuracy, shorter P300 latencies, and smaller P300 amplitudes, while intermediate batters would generate slower RTs, less accuracy, longer P300 latencies, and larger P300 amplitudes.

Method

Participants

Ten male university students (intermediate skill-level group) and 10 players from a highly ranked southeastern U.S. university baseball team (advanced skill-level group) volunteered to participate in the study. To qualify for the intermediate skill-level group, participants had to have played on their high school baseball team. Because there was a chance that a good high school player simply did not want to play at a higher level and could conceivably be better than a participant in the advanced group, further stipulations included that participants in the intermediate skill-level group had not been offered a scholarship to play at a university nor to try out with a professional minor league team and that they were not presently playing in a competitive baseball league. Four participants (two from each group) were excluded from the analysis, because excessive eye blinks contaminated their data and made analyses impossible.

Stimuli

A Sharp projection unit presented a sequence of baseball pitches via a Panasonic AG7350 (Panasonic, Tokyo, Japan) VCR tape player onto a 182.88- x 243.84-cm white screen. The height and size of the projected baseball pitcher were adjusted to reflect a life-like representation of how a pitcher would appear standing the regulation 1,844.04 cm away from the batter. Participants sat in a chair 150 cm away from the screen. The right-handed pitcher was of college-level caliber and had pitched for the USA national team the previous season. None of the participants in the intermediate or advanced skill level group had prior experience facing the filmed pitcher. Twenty fastballs and 20 curveballs were randomly presented throughout the videotape, with each pitch being shown 10 times. Thus, participants viewed a total of 400 pitches. The videotape of the fastballs and curveballs was spliced so that an equal amount of time (8 s) would separate each pitch.

Instrumentation

Electrodes implanted within an Electrocap (ECI, Inc., Santa Barbara, CA) detected and relayed electrocortical information to a Biopac Systems, Inc., (EEG100A) unit, which amplified the signals 50,000 times. Once amplified, the EEG signals were sampled by a Biopac Systems, Inc., module MP100 and then relayed to a Macintosh IIx computer. The software used for data collection and processing was Acknowledge 3.0 (Biopac Systems, Inc., Santa Barbara, CA). EEG measurements were taken from the P_z location, with the right earlobe as a common reference. The P_z location corresponded with the 10-20 International System for electrode placement (Jasper, 1958). Electro-oculography (EOG) electrodes were placed below and to the left of the left eye. All signals were sampled at 200 Hz and stored on magnetic tape.

The P_z location was used to record P300 latency and amplitude. This electrode site has been reliable for investigating P300 latency and attentional processing (Johnson, Pfefferbaum, & Kopell, 1985; McCarthy & Donchin, 1981). The remaining channels were used for another experiment investigating lateralized readiness potentials. The EEG at P_z was digitally lowpass filtered at 3.4 Hz (-3dB attenuation) and averaged for all combinations of conditions (type of precue and pitch) resulting in six averaged waveforms. Only correct responses were averaged.

P300 amplitude was quantified as the difference between the most positive value between 150 and 500 ms after stimulus onset and the average value within the 100 ms prior to stimulus onset. Stimulus onset was considered to be the first exposure to the baseball, which mainly occurred when the pitcher was winding up and the ball in his pitching hand in his ear region. The videotape was manufactured to time-lock the moment of stimulus onset by inserting an impulse of white noise onto one of the tape's audio channels. This marker would appear on one of the data collection channels, thus allowing the capabilities of time-locking the ERP information with the initial presentation of the pitch. An ERP was considered artifact-free, if the range of the EOG activity between 100 ms before and 500 ms after stimulus onset did not exceed 50 μV.

Participants responded by pressing one of two buttons, one on each arm of the chair. Participants within their respective groups were randomly assigned to respond with either their right index finger for a fastball and their left index finger for a curveball or with their left index finger for a fastball and their right index finger for a curveball. A press of a button sent a low-voltage signal to the computer and was displayed as an impulse on a separate channel for comparison to the EEG and EOG data.

Procedure

On arrival at the Motor Behavior Laboratory, participants read and sign an informed consent form. They were then permitted to become familiar with the laboratory surroundings as well as the EEG and electromyographic (EMG) equipment. Once they were comfortable, the sequence of the application of the EEG and EOG electrodes was explained and any questions were answered.

The connection process began by cleaning the locations where the EOG and reference electrodes would be placed. Each participant's head was measured, and different size electrocaps selected according to the participant's head size. Electrogel (ECI, Inc., Santa Barbara, CA) was applied to lower impedance, and a reference electrode was attached to the right earlobe. All EEG electrode sites were then checked with a Grass Instruments Electrode Impedance Meter (Model EZM5AB; Grass Instruments, West Warwick, RI) to ensure that impedance levels were below 5 K ohms. The EOG electrodes were then connected above and below the participant's left eye.

After the connections were completed, participants sat comfortably in a chair and were told to relax, with their eyes open, while baseline measurements were recorded. After 2 min, they listened to verbal instructions about how to respond to the fastballs and curveballs. Participants were instructed to press one of the two buttons as fast as possible once they had decided whether the pitch was a fastball or curveball. Determining which button participants would press to indicate the type of pitch was predetermined via a random selection. The participant was then instructed to use this hand-pitch combination for all 400 pitches. Response speed and accuracy were stipulated.

The precuing instructions were given verbally. Participants were informed that during the 8-s rest period between pitches they would be told if a fastball or curveball would be presented next. On 75% of the pitches a precue was offered, while no precue was given on 25%. When a precue was presented, it was valid (correct) 75% of the time and invalid (incorrect) 25% of the time. In this manner, six conditions were created: (a) valid precued fastball; (b) valid precued curveball; (c) invalid precued fastball; (d) invalid precued curveball; (e) no-precued fastball; and (f) no-precued curveball. All participants were aware that they would not receive a precue for some pitches and sometimes they would receive a correct or incorrect precue. Their questions were then answered.

After receiving instructions, participants performed 20 practice trials followed by 10 blocks of 40 pitches, for a total of 400 pitches. A 5-min break separated each trial block, and an 8-s rest period separated each trial. During the between-trial rest period, the screen displayed a solid black image.

Results

Mean averages were computed for all combinations of conditions for each participant, yielding a breakdown of total trials for each condition as follows: 120 valid fastballs, 120 valid curveballs, 30 invalid fastballs, 30 invalid curveballs, 50 no-precued fastballs, and 50 no-precued curveballs. Separate analyses of variance (ANOVAs) were conducted for P300 amplitude, P300 latency, and reaction time (RT). For all ANOVAs with repeated measures, the conservative F test correction for degrees of freedom was applied (Greenhouse & Geisser, 1959). To assess the meaningfulness of significant main effects and interactions η^2 was used. The alpha level was .05 for all statistical tests. Significant interactions were subjected to a simple effects test (Keppel, 1982), and main effects were subjected to Tukey's HSD post hoc test, when appropriate. Because the accuracy data was proportional in nature and its distribution binomial, an arcsin transformation was performed followed using a repeated-measures ANOVA.

P300 Amplitude

The P300 amplitude values were entered into a 2 (Skill Level) x 3 (Precue) x 2 (Pitch) ANOVA with repeated measures on the last two variables. The test indicated that skill level interacted with precue and type of pitch, $F(2, 28) = 3.89$, $p < .04$, $\mu^2 = .37$. As shown in Figure 1, intermediate batters produced significantly larger P300 amplitudes for all Precue x Curveball conditions than the advanced batters did for all Precue x Curveball conditions. The largest amplitude changes occurred when intermediate batters responded to a curveball using an invalid precue (M = 8.7 μV, SD = .69) followed by a no-precued curveball (M = 8.5 μV, SD = .60; i.e., a fastball was precued but a curveball was presented) and last by a valid precued curveball (M = 7.2 μV, SD = .96). On the other hand, advanced batters produced significantly smaller P300 amplitudes for an invalid precued curveball (M = 6.0, SD = .39), a no-precued curveball (M = 5.9, SD = .52), and a valid precued curveball (M = 5.4, SD = .91).

P300 Latency

Once averaged, P300 latency was determined to be the time in ms from stimulus onset to the apex of the waveform. A 2 (Skill Level) x 3 (Precue) x 2 (Pitch) ANOVA with repeated measures on the last two factors revealed a Precue x Pitch interaction and a main effect for skill level. For the Precue x Pitch interaction, $F(2, 28) = 6.22$, $p < .0001$, $\mu^2 = .45$, the invalid precued curveball (M = 412.6 ms, SD = 59.8), no-precued curveball (M = 393 ms, SD = 56.2), invalid precued fastball (M = 375.5 ms, SD = 47.7), and valid precued curveball (M = 363.1 ms, SD = 48.5) conditions created longer P300 latencies than did the no-precued fastball (M = 339.2 ms, SD = 45.9) and valid precued fastball (M = 316.6 ms, M = 41.3) conditions. The no-precue condition produced the greatest P300 latency effect, compared to the valid and invalid precue conditions, with regard to whether fastballs or curveballs were thrown. Mean scores by precue condition may be found in Figure 2. The skill level main effect, $F(1, 14) = 9.90$, $p < .001$, $\mu^2 = .54$, showed that the intermediate group produced shorter latencies (M = 348.6 ms, SD = 53.2) than did the advanced group (M = 384.7 ms, SD = 45.8).

Reaction Time and Accuracy

A 2 (Skill Level) x 3 (Precue) x 2 (Pitch) ANOVA with repeated measures conducted on the last two factors resulted in three significant main effects and two interactions. For the Skill Level x Pitch interaction, $F(1, 14) = 8.17$, $p < .02$, $\mu^2 = .37$, the intermediate batters responded slower (M = 313.5, SD = 9.99) than the advanced batters (M = 292.1, SD = 9.88) for the curveball, while there was little difference between the intermediate batters (M = 240.3, SD = 16.0) and the advanced batters (M = 235.8, SD = 16.2) for the fastball. Figure 3 depicts this interaction.

A Precue x Pitch interaction, $F(2, 28) = 3.67$, $p < .05$, $\mu^2 = .21$, revealed that all batters responded faster using valid precued curveballs (M = 285.5, SD = 15.81) as compared to invalid precued curveballs (M = 314.8, SD = 15.95) and no-precued curveballs (M = 308.1, SD = 12.93). The interaction is shown in Figure 4.

To determine if there was a difference in the accuracy of responding between the intermediate and advanced group, a 2 (Skill Level) x 3 (Precue) x 2 (Pitch) ANOVA with repeated measures on the last two factors was performed. This test indicated 3 significant main effects. For skill level, $F(1, 14) = 6.91$, $p < .02$, $\mu^2 = .33$, the advanced

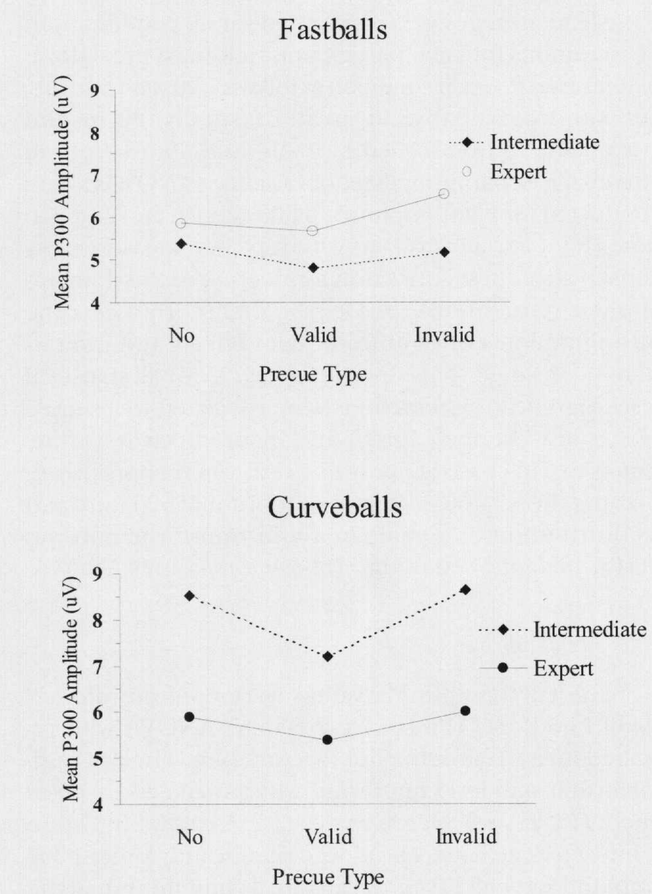

Figure 1. Mean P300 amplitude for fastballs (top) and curveballs (bottom) as a function of skill level and type of precue.

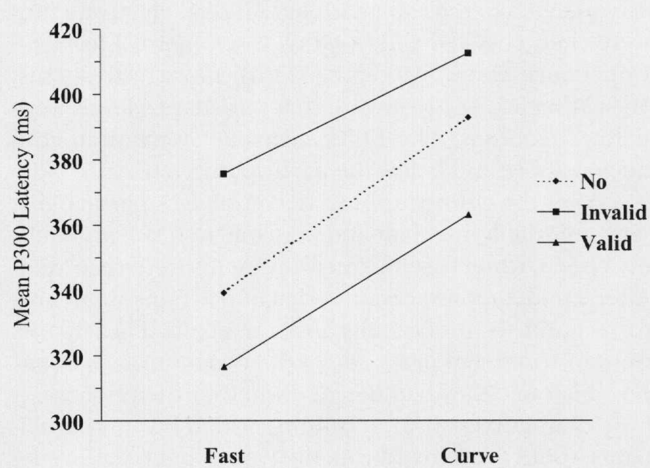

Figure 2. Mean P300 latency as a function of type of precue and type of pitch.

batters responded with more accuracy (94.1 %) than the intermediates (87.8%). For precue, $F(2, 28) = 33.77$, $p < .0001$, $\mu^2 = .71$, batters were less accurate with an invalid precue (81.1%) as opposed to using a valid precue (94.1%) or no precue (92.2%). A pitch main effect, $F(1, 14) = 8.11$, $p < .02$, $\mu^2 = .37$, showed that batters responded less accurately when a curveball was thrown (88%) as opposed to a fastball (91%).

Discussion

The present experiment was designed to examine the perceptual decision-making skills of advanced and intermediate baseball batters after they received precued information about an upcoming pitch. Accordingly, RTs, accuracy scores, and ERPs were collected on baseball batters as they responded to a filmed pitching opponent. Findings supported a limited capacity model of attention and have implications for future psychophysiological sport studies involving ERPs and a dynamic viewing situation[1].

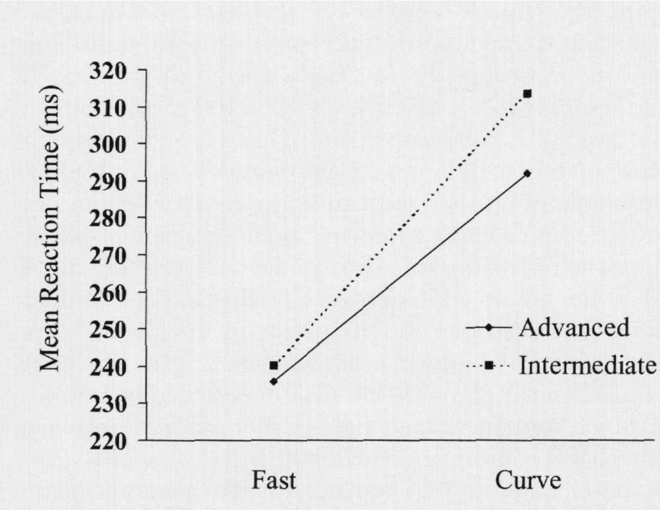

Figure 3. Mean response time as a function of skill level and type of pitch.

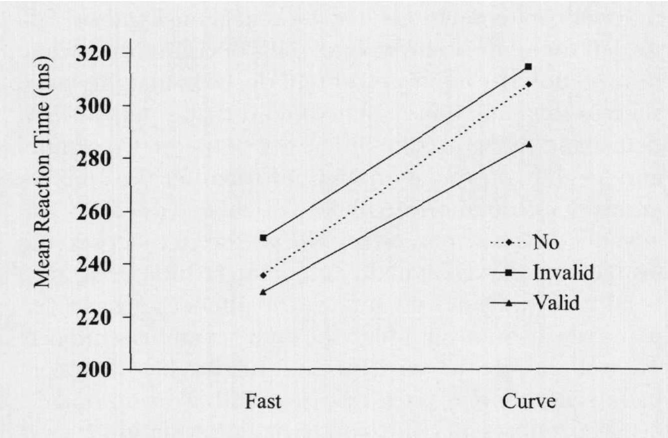

Figure 4. Mean response time as a function of type of precue and type of pitch.

In agreement with previous findings using a cost-benefit paradigm in sports, RT for both skill level groups resulted in the familiar costs and benefits of anticipation. The valid precued condition facilitated responding, while the invalid precued condition resulted in slower RTs. Comparison between the two skill levels across all precue conditions, however, showed that the advanced batters responded faster and with more accuracy than the intermediates, suggesting an enhanced ability to perceive the type of pitch being thrown as well as to select and initiate the correct response.

The interaction between skill level and precued condition produced an interesting result. Although intermediates and advanced batters responded relatively similar in the fastball conditions, the speed of advanced batters to recognize curveballs was significantly greater than the intermediates. From an information processing perspective, it could be argued that the advanced batters' increased experience with viewing curveballs evoked an enhanced recognition schema or memory template, thus allowing for quicker access to memory stores (Williams, Davids, & Williams, 1999). By more quickly recognizing the type of pitch, increased time is allotted to response selection before having to initiate the response, consequently leading to an enhanced ability to efficiently select a correct response. It should be noted though, that the mean RT values for both the intermediate and expert players' response to a fastball were extremely fast (approx. 240 ms). This amount of time is generally needed to respond to simple stimuli, such as the illumination of one of two lights. Thus, it is possible that participants partially based their decision on information before their first exposure to the ball.

With regard to the ERP data, the precue manipulations resulted in different profiles between the intermediate and advanced batters. Overall, the advanced group appeared to process information more quickly, evidently consuming relatively less attentional resources available in the decision-making process while continuing to evaluate the visual information beyond the point at which a decision had been overtly initiated. Most likely, it could be argued that the advanced batters were able to recognize more effectively the redundancies evident between the differing perceptual patterns produced by the curve and fast balls, thus facilitating processing automation and reducing the information processing load imposed on them. For instance, Abernethy and Russell (1987) showed that expert badminton players were able to extract contextually relevant information (e.g., the angle of the hitting arm) earlier than novice players. They suggested that because experts "pick up" task-relevant information faster, their information-processing load is reduced, thus producing faster response times.

The most noticeable difference between the ERP profiles of the intermediate and advanced batters was in their P3 amplitude changes to a curveball as opposed to a fastball. P3 amplitude can be used to index the demands on a person's attentional capacity resources (Donchin & Cohen, 1967; Hoffman et al., 1983; Israel et al., 1980; Squires et al., 1977). The intermediate batters produced very large amplitudes (> 8.13 μv) in all the curveball conditions. On the other hand, the advanced cues or presentation of the pitch did not seem to influence the advanced batters. They generated much smaller P3s (< 5.80 μV) in all curveball conditions. This finding can be explained using a limited capacity model of attention. Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977) proposed two classes of processing mechanisms: automatic, and controlled. Automatic processes are fast, inflexible, and consume little attentional capacity. Conversely, controlled processes are slow, attentionally demanding, and controlled by the participant's intentions. In line with this idea, sport researchers believe one reason high-level athletes can attend to and process the most relevant information within a highly dynamic sport situation is that they have the ability to allocate a sufficient amount of attention to the most pertinent information (Abernethy, 1993). This type of processing is essentially conducted automatically, and these athletes consequently have enough "attentional reserve" to allocate to secondary perceptual information or for early response preparation processes (e.g., Abernethy, 1993). Lesser skilled performers, on the other hand, need to allocate most, if not all, their attentional resources to the task at hand. Thus, it is believed that the large P3s produced by the intermediate batters reflects a more limited attentional capacity.

Johnson (1986) offered an alternative explanation for the mechanisms responsible for large P3 amplitudes. His Triarchic model posits that three dimensions influence P300 amplitude: (a) subjective probability, (b) stimulus meaning, and (c) information transmission. Variables affecting the subjective probability (a priori probability, sequential effects) and stimulus meaning (task complexity, stimulus complexity, stimulus value) dimensions have independent and additive contributions to overall P3 amplitude. However, a multiplicative relation with the proportion of transmitted stimulus information modulates the amplitude contributions of both these dimensions.

Applying Johnson's model, it is possible, then, that the amount of information transmitted and filtered to higher decision-making centers of the brain is greater for advanced than intermediate batters. This factor and the complexity of the stimulus display are likely candidates for a large P3. Consequently, detecting between a curveball and a fastball in such a dynamical presentation of visual information and speeded response requirement appeared to consume more of the intermediates' attentional capacity compared to the advanced batters. Thus, when intermediates anticipated a fastball coming, it is likely that they were somewhat "surprised" if a curveball was thrown. This surprise effect consumes much attentional capacity and increases the magnitude of P300 (Donchin, 1981). Advanced batters, on the other hand, appeared to have greater attentional flexibility, which allowed them to reduce the effects of the invalid precues.

The amount of information transmitted and processed between the two skill-level groups can also be interpreted through the latency of P300 (Campbell et al., 1979; Ritter et al., 1979; Verleger, 1997), which has served as a measure of encoding time that is uncontaminated by response processes (McCarthy & Donchin, 1981). Its latency is an index of when stimulus evaluation processes terminate and when motor response preparation begins. The present study showed that intermediate batters produced faster P3s than the advanced batters for all precuing conditions (349 vs. 385 ms). At first glance, it could be concluded that intermediates finished evaluating the baseball pitch earlier than advanced batters. However, after analyzing the RT and accuracy data, an alternative conclusion was accepted. Compared with the advanced group, the intermediate group generated slower RTs (283 vs. 265 ms) and with less accuracy (87.8 vs. 94.1%) in all precued conditions. These findings, in conjunction with larger P3 amplitudes, suggest that intermediates finished evaluating the ball earlier but did not transmit adequate information for efficient responding. The reason intermediates processed less information than the advanced batters may be due to their limited attentional capacity and their inability to effectively update contextual information. Further, it is possible that the advanced players' extensive experience in viewing fastballs and curve balls helped them more effectively match visual information about the ball (e.g., speed, seam rotation, trajectory) to templates stored in memory. Therefore, because this task did not overwhelm the advanced batters' perceptual attentional resources, they could afford more time for template-matching.

Another possible explanation as to why advanced batters produced longer P300 latencies yet faster RTs and more accurate decisions may be that their expertise afforded them the ability to base their decisions on partial information. In rapid perceptual decision-making tasks such as this one, one could contend that a person may detect and recognize the difference between two stimuli and be able to process enough information (i.e., bits or grains of information) to make a calculated decision. An advanced batter, perceiving the difference between a fastball and curveball in an automatic fashion, may only need to see a visual cue, such as the pitcher's arm angle, to make a decision, although the entire stimulus sequence was not entirely viewed. Thus, we suggest that advanced batters differentiate pitch type essentially in an automatic fashion and base decisions on partial information.

In conjunction with investigating decision-making and attentional mechanisms involved in dynamic sport settings, this study supports other recent efforts by sport psychology researchers to effectively collect ERP data of athletes viewing a dynamic situation pertaining to their specific sport (e.g., Melnikov & Singer, 1998). Previous sport researchers have collected ERP data to measure differences in athletes from different sports, but the viewing situations presented to the athletes were either simple visual stimuli commonly used in cognitive psychology experiments (Zani & Rossi, 1991) or self-paced, closed motor activities, such as an isometric arm flexion (Konttinen, Lyytinen, Haapamaeki, Kyyrae, & Viitasalo, 1997) or shooting performances (Konttinen & Lyytinen, 1992, 1993; Konttinen, Lyytinen, & Era, 1999; Konttinen, Lyytinen, & Konttinen, 1995). The method pioneered in the present experiment[2] and the results found make a strong case for extending the collection of ERP data to other reactive activities, such as receiving a volleyball or tennis serve, detecting offensive or defensive pattern formations in football, and goaltending in hockey or soccer. Furthermore, collection of ERP data could help to evaluate strategies to improve a performer's mental approach within his or her sport.

References

Abernethy, B. (1993). Searching for the minimal essential information for skilled perception and action. *Psychological Research, 55,* 131–138.

Abernethy, B., & Russell, D. G. (1987). Expert-novice differences in an applied selective attention task. *Journal of Sport Psychology, 9,* 326–345.

Adair, R. K. (1994). *The physics of baseball* (2nd ed.). New York: Harper-Perennial.

Bahill, A. T., & LaRitz, T. (1984). Why can't batters keep their eyes on the ball? *American Scientist, 72,* 249–253.

Bard, C., & Fleury, M. (1981). Considering eye movement as a predictor of attainment. In I. M. Cockerill & W. W. MacGillivary (Eds.), *Vision and sport* (pp. 28–41). Cheltenham, UK: Stanley Thornes.

Burroughs, W. A. (1984). Visual simulation training of baseball batter. *International Journal of Sport Psychology, 15,* 117–126.

Campbell, K. B., Courchesne, E., Picton, T. W., & Squires, K. C. (1979). Evoked potential correlates of human information processing. *Biological Psychology, 8,* 45–68.

Castiello, U., & Ùmilta, C. (1992). Orienting of attention in volleyball players. *International Journal of Sport Psychology, 23,* 301–310.

Davids, K., Williams, A. M., Button, C., & Court, M. (in press). An integrative modeling approach to the study of intentional movement behavior. In R. N. Singer, H. A. Hausenblas, & C. M. Janelle (Eds.), *Handbook of research on sport psychology* (2nd ed). New York: Wiley.

Donchin, E. (1981). Surprise! Surprise? *Psychophysiology, 18,* 493–513.

Donchin, E., & Cohen, L. (1967). Averaged evoked potentials and intramodality selective attention. *Electroencephalography and Clinical Neurophysiology, 22,* 537–546.

Goulet, C., Bard, C., & Fleury, M. (1989). Expertise differences in preparing to return a tennis serve: A visual information processing approach. *Journal of Sport and Exercise Psychology, 11,* 382–398.

Greenhouse, S. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24,* 95–112.

Hanson, T. (1991). *The mental aspects of hitting.* Unpublished doctoral dissertation, University of Virginia, Charlottesville.

Hoffman, J. E., Simons, R. F., & Houck, M. R. (1983). Event-related potentials during controlled and automatic target detection. *Psychophysiology, 20,* 625–632.

Hyllegard, R. (1991). The role of baseball seam pattern in pitch recognition. *Journal of Sport and Exercise Psychology, 13,* 80–84.

Israel, J. B., Chesney, G. L., Wickens, C. D., & Donchin, E. (1980). P300 and tracking difficulty: Evidence for multiple resources in dual-task peformance. *Psychophysiology, 17,* 259–273.

Jasper, H. H. (1958). The ten-twenty electrode system of the International Federation. *Electroencephalography and Clinical Neurophysiology, 10,* 371–375.

Johnson, R., Jr. (1986). A triarchic model of P300 amplitude. *Psychophysiology, 23,* 367– 384.

Johnson, R., Jr., Pfefferbaum, A., & Kopell, B. S. (1985). P300 and long-term memory: Latency predicts recognition performance. *Psychophysiology, 22,* 497–507.

Keppel, G. (1982). *Design and analysis: A researcher's handbook.* Englewood Cliffs, NJ: Prentice-Hall.

Konttinen, N., & Lyytinen, H. (1992). Physiology of preparation: Brain slow waves, heart rate, and respiration preceding triggering in rifle shooting. *International Journal of Sport Psychology, 23,* 110–127.

Konttinen, N., & Lyytinen, H. (1993). Individual variability in brain slow wave profiles in skilled sharpshooters during the aiming period in rifle shooting. *Journal of Sport and Exercise Psychology, 15,* 275–289.

Konttinen, N., & Lyytinen, H., & Era, P. (1999). Brain slow potentials and postural sway behavior during sharpshooting performance. *Journal of Motor Behavior, 31,* 11–20.

Konttinen, N., Lyytinen, H., Haapamaeki, J., Kyyrae, M., & Viitasalo, J. (1997). Brain slow potentials preceding an isometric maximal arm flexion. *International Journal of Sport Psychology, 28,* 287–299.

Konttinen, N., & Lyytinen, H., & Konttinen, R. (1995). Brain slow potentials reflecting successful shooting performance. *Research Quarterly for Exercise and Sport, 66,* 64–72.

Kutas, M., McCarthy, G., & Donchin, E. (1977). Augmenting mental chronometry: The P300 as a measure of stimulus evaluation time. *Science, 197,* 792–795.

Lee, D. N. (1976). A theory of visual control of braking based on information about time-to-collision. *Perception, 5,* 437–459.

Lee, D. N. (1980). Visuomotor coordination in space time. In G. E. Stelmach and J. Requin (Eds.), *Tutorials in motor behavior* (281–295). Amsterdam: Elsevier.

Lee, D.N. (1990). Getting around with light and sound. In R. Warren & A. H. Wertheim (Eds.), *Perception and control of self-motion* (487–505). Hillsdale, NJ: LEA.

McCarthy, G., & Donchin, E. (1981). A metric for thought: A comparison of P300 latency and reaction time. *Science, 211,* 77–80.

McPherson, S. L., & French, K. E. (1991). Changes in cognitive strategies and motor skill in tennis. *Journal of Sport and Exercise Psychology, 13,* 26–41.

Melnikov, A. V., & Singer, R. N. (1998). Analysis of event-related potentials to filmed action situations. *Research Quarterly for Exercise and Sport, 69,* 400–405.

Meyer, D. E., Osman, A. M., Irwin, D. E., & Yantis, S. (1988). Modern mental chronometry. *Biological Psychology, 26,* 3–67.

Nougier, V., & Rossi, B. (1999). The development of expertise in the orienting of attention. *International Journal of Sport Psychology, 30,* 246–260.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32,* 3 –25.

Pritchard, W. S. (1981). Psychophysiology of P300. *Psychological Bulletin, 89,* 506–540.

Ripoll, H. (1988). Analysis of visual scanning patterns of volleyball players in a problem solving task. *International Journal of Sport Psychology, 19,* 19–25.

Ritter, W., Simson, R., Vaughan, H. G., & Friedman, D. (1979). A brain event related to the making of a sensory discrimination. *Science, 203,* 1358–1361.

Savelsbergh, G. J. P., & Bootsma, R. J. (1994). Perception-action coupling in hitting and catching. *International Journal of Sport Psychology, 25,* 331–343.

Savelsbergh, G. J. P., & Whiting, H. T. A. (1988). The effect of skill level, external frame of reference, and environmental changes on one-hand catching. *Ergonomics, 31,* 1655–1663.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84,* 1–66.

Shank, M. D., & Haywood, K. M. (1987). Eye movements while viewing a baseball pitch. *Perceptual and Motor Skills, 64,* 1191–1197.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84,* 127 –190.

Singer, R. N., Williams, A. M., Frehlich, S. G., Janelle, C. M., Radlo, S. J., Barba, D. A., & Bouchard, L. (1998). New frontiers in visual search: An exploratory study in live tennis situations. *Research Quarterly for Exercise and Sport, 69,* 290–296.

Squires, N. K., Donchin, E., Squires, K. C., & Grossberg, S. (1977). Bisensory stimulation: Inferring decision-related processes from P300 component. *Journal of Experimental Psychology: Human Perception and Performance, 3,* 299–315.

Tresilian, J. R. (1990). Perceptual information for the timing of interceptive action. *Perception, 19,* 223–239.

Tresilian, J. R. (1991). Empirical and theoretical issues in the perception of time to contact. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 865–876.

Tresilian, J. R. (1993). Four questions of time to contact: A critical examination of research on interceptive timing. *Perception, 22,* 653–680.

Tresilian, J. R. (1994). Approximate information sources and perceptual variables in interceptive timing. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 154–173.

Verleger, R. (1997). On the utility of P3 latency as an index of mental chronometry. *Psychophysiology, 34,* 131–156.

Williams, A. M., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in soccer. *Research Quarterly for Exercise and Sport, 69,* 111–128.

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual perception and action in sport.* London: E & FN Spon.

Williams, A. M., Davids, K., Burwitz, L., & Williams, J. G. (1994). Visual search strategies in experienced and inexperienced soccer players. *Research Quarterly for Exercise and Sport, 65,* 127–135.

Zani, A., & Rossi, B. (1991). Cognitive psychophysiology as an interface between cognitive and sport psychology. *International Journal of Sport Psychology, 22,* 376–398.

Notes

1. Contemporary ecological accounts for perception and action are a viable means to describe and explain one's capability to recognize and respond to visual stimuli. Among other work, scientific induction regarding the variable tau and its relation to different receptive and interceptive actions (e.g., Lee, 1976, 1980, 1990; Savelsbergh & Bootsma, 1994; Savelsbergh & Whiting, 1988; Tresilian, 1990, 1991, 1993, 1994) provides ample evidence (from an ecological orientation) equally as valid as indirect approaches for explaining how reactive tasks are performed. However, the involvement of ERPs as a measure or account for these theoretical approaches is virtually nonexistent. Therefore, although inappropriate to suggest that the study of ERPs does not fit with the conceptual frameworks of ecological accounts of movement, it is important to emphasize that, to date, the interpretation of time-locked cortical potentials has not been a focus within perception-action theory. In contrast, the entire theoretical framework surrounding the significance of the various ERP waveforms is grounded in cognitively oriented information processing models, with structural (i.e., biological) links. Indeed, mental chronometry, as its name suggests, implies a stage orientation to acquiring and processing information. Although ecological accounts could certainly describe the behavioral aspects of performance, the current psychobiological interpretation of ERPs is difficult, if not impossible, to frame within an ecological context. With these considerations in mind, more recent ecological approaches to describing perception and action have begun to embrace issues raised by indirect perception theorists concerning how cognitions, intentions, and emotions provide control parameters on self-organizing systems. Davids, Williams, Button, and Court (in press), have proposed a newly integrative modeling approach to describe perception and action in which a principal notion is that intentions and emotions constrain the systems determining movement, thereby providing control parameters influencing the organization of response systems. In accordance with this and other neo-ecological accounts, future investigations in which ERPs and other indexes of cortical activation profiling may be used and interpreted in the context of perception-action and dynamic accounts of coordination are certainly warranted and probable.

2. It should be noted that the research by Alexander V. Melnikov and Robert N. Singer printed in the December 1998 issue of *Research Quarterly for Exercise and Sport* was the pilot data for the present research. All investigators in the present experiment contributed to the theoretical and methodological development of testing the viability of collecting ERPs, while participants viewed video simulations of sport-specific situations.

Authors' Note

Please address all correspondence concerning this article to Steven J. Radlo, Department of Physical Education, 221-D Brophy Hall, Western Illinois University, Macomb, IL 61455.

E-mail: steven_radlo@wiu.edu