Event-related potential effects of superior action anticipation in professional badminton players

Hua Jin\textsuperscript{a,b}, Guiping Xu\textsuperscript{a}, John X. Zhang\textsuperscript{c}, Hongwei Gao\textsuperscript{a}, Zuoer Ye\textsuperscript{a}, Pin Wang\textsuperscript{a}, Huiyan Lin\textsuperscript{a}, Lei Mo\textsuperscript{a,*,1}, Chong-De Lin\textsuperscript{b,*,1}

\textsuperscript{a} Center for Studies of Psychological Application, South China Normal University, Guangzhou 510631, China
\textsuperscript{b} State Key Laboratory of Cognitive Neurosciences and Learning, Beijing Normal University, Beijing 100875, China
\textsuperscript{c} Department of Psychology, The Chinese University of Hong Kong, Hong Kong

\section*{Abstract}

The ability to predict the trajectory of a ball based on the opponent's body kinematics has been shown to be critical to high-performing athletes in many sports. However, little is known about the neural correlates underlying such superior ability in action anticipation. The present event-related potential study compared brain responses from professional badminton players and non-player controls when they watched video clips of badminton games and predicted a ball's landing position. Replicating literature findings, the players made significantly more accurate judgments than the controls and showed better action anticipation. Correspondingly, they showed enlarged amplitudes of two ERP components, a P300 peaking around 350 ms post-stimulus with a parietal scalp distribution and a P2 peaking around 250 ms with a posterior-occipital distribution. The P300 effect was interpreted to reflect primed access and/or directing of attention to game-related memory representations in the players facilitating their online judgment of related actions. The P2 effect was suggested to reflect some generic learning effects. The results identify clear neural responses that differentiate between different levels of action anticipation associated with sports expertise.

\section*{Introduction}

In many sports that are played under high time pressure, it is important for the players to anticipate outcomes of the various actions involved, such as the opponent's actions, the moving trajectory of a ball. Many behavioral studies have shown that compared with non-players or novice players, high-performance players can better predict the outcomes of other players' sequential movements\textsuperscript{[1–5,7,11,14,25,28,30,34,36–38]}. With eye movement measures to predict the outcomes of other players' sequential movements\textsuperscript{[2,9,27]}. However, few cognitive neuroscience studies have ever examined the neural correlates underlying expert player's superior ability in action anticipation. Using functional MRI, Wright et al.\textsuperscript{[39]} reported for sports experts enhanced activity in cortical areas integral to observing and understanding others’ actions. In an event-related potential (ERP) study and focusing on one of the most widely studied P300 component, Radlo et al.\textsuperscript{[23]} asked participants to judge the type of baseball pitch thrown (fastball or curveball), and found a positive ERP deflection peaking around 300 ms after stimulus onset. P300 is hypothesized to reflect stimulus evaluation with its latency associated with the time needed for processes such as stimulus discrimination, pattern recognition, classification, and memory template matching to occur\textsuperscript{[12,13,20]}. Their results show that comparable P300 responses between intermediate and advanced batters for action anticipation. Taliep et al.\textsuperscript{[32]} asked participants to judge the pitch type of cricket (fast or slow ball) and found significantly reduced P300 latency in skilled cricket batsmen compared with less skilled batsmen. The behavioral data in this study, however, were not significantly different across the two groups. Clearly, more empirical evidence is needed to reveal whether ERP responses as neural indices would differentiate between different levels of action anticipation associated with sports expertise.

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To this end, the present ERP study compared brain responses from professional badminton players and non-player controls when they were asked to predict the landing position of a ball. Eighteen badminton players (9 female, mean age ± SD = 21.9 ± 2.0 years, range = 18–25 years) and eighteen non-badminton players (9 female, mean age ± SD = 22.8 ± 2.2 years, range = 18–27 years) participated in this study. All were right-handed with normal or corrected-to-normal vision and normal color vision. None had any neurological or psychiatric disorders. Written informed consent was obtained.

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\textsuperscript{*} Corresponding authors.
\textsuperscript{1} These authors contributed equally to this work.
following a protocol approved by IRB of South China Normal University. Participants were pre-selected based on their responses to a sports experience questionnaire. The players met all the following inclusion criteria: (1) currently playing in provincial/municipal badminton team; (2) qualified as the National Player at Second Grade or above; (3) 5 or more years of professional training experience; (4) practising more than three times a week and for 2 or more hours each time in the last 2 years. The controls matched the players in age and education but did not have any previous experience of playing badminton or tennis. They did not watch badminton or tennis games at all or only occasionally.

Stimuli were color video clips (wmv format, 25 frames per second) of single matches in world tournaments with a sample illustrated in Fig. 1. The clips subtended a visual angle of 14.2° horizontally and 11.4° vertically.

Task difficulty was manipulated by setting clip length at two levels. With a 1280-ms duration, the easy clips ended about 800 ms (+20 frames) after contact point, and the ball had finished about 1/3 or 2/3 of its trajectory from contact to touching ground. As a baseline condition, the difficulty clips were with a duration of 480 ms, ending right at the contact point. As the clips provided little visual information about the ball’s final location for people without badminton-related experience, the controls were expected to perform at chance level from pure guessing. There were 100 test clips in total, 40 in the easy and 60 in the difficult conditions (numbers not balanced due to practical reasons in material preparation). At both conditions, the ball actually landed equal-likely in one of four locations, left forecourt, right forecourt, left backcourt, and right backcourt. All clips were viewed for the first time by all participants.

Participants were tested individually in a dim sound-proof room, seated in an armchair viewing a monitor 1-meter away. They were instructed to avoid head movements and eye blinks, especially during clip presentation. In each trial, a fixation cross was first presented at screen center for 1000 ms, followed by random presentation of an easy or difficult clip. Participants were asked to view the clip with full attention and judge as quickly and accurately as possible the ball’s landing position, specifically, whether the ball would land at the forecourt or the backcourt (regardless of left or right side). Half participants pressed the ‘I’ and ‘V’ keys with index fingers to indicate a forecourt or a backcourt location. For the other half, the ‘M’ and ‘R’ keys were used to counterbalance left right hand positions. Participants performed 4 practice trials with clips not used in test and then completed 100 test trials with two self-paced breaks.

EEGs were recorded using a 32-channel Ag–AgCl electrode cap (10–20 convention) with a 500–Hz sampling rate. All electrodes were referenced online to the left mastoid and re-referenced offline to linked mastoids. Impedances were kept below 5 kΩ. Band-pass filtering (0.1–100 Hz) was applied with a 50 Hz notch filter. Eye movement artifacts were automatically corrected using the Scan software, rejecting epochs exceeding 100 μV at any electrode.

Epochs were from –200 ms to 800 ms with time 0 being clip onset (baseline correction with the first 200 ms), and averaged by condition and filtered with a 20-Hz low-pass filter. P300 amplitudes from three representative electrodes (P3, P4, Pz) were analyzed using a 2-way ANOVA (participant group × task difficulty). The same analysis was performed on a P2 component at O1, Oz, and O2. Greenhouse–Geisser correction was applied where necessary and uncorrected degrees of freedom and corrected p values were reported.

Data from two participants in each group were excluded due to artifacts or computer breakdown. Results reported below were based on sixteen players and sixteen controls. Fig. 2 shows mean reaction times (RT) for correct trials and accuracies across participant group and task difficulty. Two-way ANOVA (group × task difficulty) on accuracies revealed significant main effects for group (F1, 30 = 12.35, p < 0.005) and condition (F1, 30 = 148.72, p < 0.001), but not their interaction (F < 1). The players were more accurate than the controls in both the easy (0.82 vs. 0.73) and difficult conditions (0.61 vs. 0.51). Both groups were more accurate in the easy than the difficult condition. ANOVA on RTs showed a significant main effect for task difficulty (easy vs. difficult: 1194.84 ms vs. 1103.81 ms, f1(30) = 5.68, p < 0.05), but not for group or their interaction (F < 1).

The behavioral results indicate that the players were significantly better in predicting the ball’s landing position, compared with controls. Even in the difficult condition, the players were still more accurate than the controls who performed at chance. Apparently, although not faster, the players were able to extract more information from the visual display, possibly by making use of the opponent’s body movements to predict the outcome while the controls may rely only on information about the ball’s trajectory [8]. Consistent with our results, response accuracy was found to be more indicative of expertise in boxers than response times [24] and expert karate athletes were more accurate rather than faster than novices in action anticipation [35]. Briefly, the behavioral results replicated previous results showing superior anticipation ability in sports experts [6,7]. It is therefore reasonable to attribute the ERP response differences between the players and controls discussed next to their different levels of action anticipation.

Following previous studies [23,32], we first looked at P300 with a parietal locus. Fig. 3 shows the grand-averaged ERPs at three parietal sites highlighting P300. ANOVA on peak amplitudes (pooled over P3, P4, and Pz) showed only a main effect of group (F1, 30) = 4.04, p < 0.05), but no other effects (Fs < 1). The amplitudes were larger for the players than the controls at both the easy (5.49 μV vs. 1.86 μV) and the difficult conditions (5.62 μV vs. 3.51 μV). For latency, there was a main effect of group with boarder line significance (F1, 30) = 3.35, p = 0.07), being shorter for the players than controls (easy: 338 ms vs. 352 ms; difficult: 340 ms vs. 364 ms).

As in Taliep et al. [32], our results tend to show a reduced P300 latency for the players compared with the controls. Not found in theirs was a more salient effect of P300 enhancement for the players. One possible reason is the expertise difference across their skilled and unskilled batman participants was not as big as that in our professional players and non-players controls. This may also be why they failed to observe any behavioral differences across their participant groups while we did.

P300 is usually examined within oddball paradigms elicited by rare stimuli. Lorenzo-López et al. [16] reported a larger P300 in a visual attention task for high-performing participants compared with low-performing participants. P300 amplitude enhancement has been found for better memory recognition and for conditions engaging lower memory load [18,20,29]. It is possible that more efficient processing in the experts compared with the controls may improve memory encoding or reduce memory load, resulting in the larger P300 we observed. In addition, anticipatory information pick-up is linked to highly developed domain-specific memory structures [40]. Expert players should have developed a large store in long-term memory of game scenarios and be able to rapidly recognize and classify an actual scenario based on such memories, aiding their online judgment of related actions. That is, the P300 effect reflects a difference in the ability of players and controls to analyze action kinematics for anticipation.

There is a problem with this explanation in that it is known from the temporal occlusion literature [39] that the relevant action kinematics determining anticipatory performance in badminton occur from around ~160 to 0 ms, which would start 320 ms from clip onset in the present study, too late to account for the P300 effect. For the same reason, the P300 effect cannot reflect retrieval
Fig. 1. Snapshots of a clip (1280 ms in length) illustrating stimuli used in the experiment. Numbers on each frame indicate the time range of each frame (40 ms per frame). Neither the numbers nor the white square occluding the face appeared in actual experimentation. Frames shown were cropped removing non-crucial image edges for the sake of illustration.

Fig. 2. Mean behavioral responses for the two groups of participants. Bars indicate standard errors. The two levels of task difficulty were plotted separately.
Fig. 3. Grand-averaged ERP waveforms for the two groups of participants highlighting the P300 component at three representative electrodes. The two levels of task difficulty were plotted separately.

of specific memory representations of such action kinematics to match with perceptual input as the latter would be missing until 300 ms onwards from clip onset. Still, different from most temporal occlusion studies using a player’s perspective, our clips consisted of a spectator’s view of continuous play. There therefore may be anticipatory cues present from stimulus onset—for example in the relative positions of the two players, and the trajectory of the shuttle prior to racquet contact. This was confirmed in a separate behavioral study displaying the clips from −480 to −80 ms and found significantly above-chance level performance in the players (players: 0.59 (0.19), controls: 0.49 (0.29), by item-analysis \( t(234) = 3.40, p < 0.001 \)). A related possibility is that when the players know a stroke is about to be played, they at the start of a trial would pre-activate their memory about action kinematics and related mental representations and/or by directing their attention to such internal representations so as to facilitate later analysis of the kinematics and shuttle trajectory. If this is the case, one would predict no P300 effect in a control task not requiring such pre-activations, such as determining which side the racquet was held [39].

Alternatively, expert players may be more motivated, more aroused, and more vigilant than controls and the P300 effect we observed reflects general motivational factors. This possibility had not been attended to previously [23,32] and we were unable to confirm it with the present data. A control task can be implemented to address this issue, for example, by using a non-badminton clip randomly interleaved with badminton clips. Both types of clips should give an enhanced P300 if the effect truly resulted from higher motivation in the players.

Note there should be no ERP differences between the easy and the difficult conditions −480 ms in controls prior to contact point as they involved exactly the same stimulation during this period. It is a bit puzzling that in the parietal regions, particularly towards Pz and P4, the two conditions differed significantly prior to contact point. This was a problem in our dataset tentatively attributed to unknown artifacts.

Other than P300, a posterior P2 occurring around 240 ms was also found to differentiate between the two groups. Fig. 4 shows the grand-averaged ERPs at three occipital sites highlighting P2. ANOVA on peak amplitudes (pooled over O1, O2, and Oz) showed a significant main effect of group \( (F_{1,30} = 6.86, p = 0.01) \), but no other effects \( (Fs < 1) \). The amplitudes were larger for the players than the controls in both the easy (10.13 vs. 6.68) and the difficult conditions (9.90 vs. 6.39). For latency, the main effect of group reached significance \( (F_{1,30} = 8.46, p < 0.01) \), being longer for the players than the controls (easy: 247 ms vs. 228 ms; difficult: 251 ms vs. 231 ms).

The nature of this posterior P2 remains unclear in the ERP literature [17]. Some associate it with the initiation of stimulus evaluation and decision-making [15,19,21,22]. Importantly, there are reports of P2 enhancement following phonological training [33] or in musicians compared with non-musicians in a tone discrimination [26]. Increased parietal-occipital P2 was also found for
Fig. 4. Grand-averaged ERP waveforms for the two groups of participants highlighting the P2 component at three representative electrodes. The two levels of task difficulty were plotted separately.

increased training time in perceptual learning [31]. Based on these results, the P2 effect is likely to reflect some generic learning effects. It remains a puzzle why P2 latency was longer for the players than the controls as one would not expect the controls to start stimulus evaluation earlier than the players.

In summary, the present study presented professional badminton players and control participants with video clips related to badminton playing. Compared with the controls, the players showed better predication of the landing position of a flying ball. The superior ability of action anticipation in the players was found to be associated with an enhanced P300 effect with a parietal scalp distribution and an enhanced and delayed P2 effect with a posterior-occipital distribution.

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