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Perceptual Judgments for Table Tennis Serve Recognition: An Event-Related Potentials Study

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Abstract: In the present study, visual attention processes in complex, sport-related decision-making tasks were examined. Psychophysiological and performance data recorded from 15 advanced table tennis athletes and 15 intermediate level undergraduates were compared. A total of 240 three-dimensional pictures of stimuli composed of a white ball and hitting location (black shade point) were presented via a screen, in which 25% represented side-backspin serves, and the other 75% represented non-side-topspin serves. Participants were instructed to report the types of serves. The results indicated that table tennis athletes responded more quickly and accurately. C1 and P1components were induced in the occipital region, N1 in the central region, and P3 in all regions. For table tennis athletes, in the phase of early sensory processing for stimuli features (such as hitting location), the cerebral cortex was activated at a higher level in comparison with undergraduates. This may be caused by the long-term exercise training. Athletes have to be very sensitive to the physical features of relevant movement stimuli. In the phase of recognizing stimuli structures or patterns, advanced athletes' cerebral cortexes were activated higher and faster. This may help them more effectively match visual information about serves to patterns stored in long-term memory.

Keywords: table tennis athletes; recognizing the types of serves; event-related potentials

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1. Introduction

The ability to perceive visual information is very important when individuals have to perceive and perform in a limited time in sports. Performers were asked to exact task-specific structures or patterns from a whole technical motion [1], so many perceptual processes were involved, such as attention process, stimulus identification, pattern recognition and memory template matching.

Backspin, topspin and sidespin are three basic rotation types when a table tennis ball is flying; according to kinematics principle, these rotation types depend on the point, direction and intensity of force. The mean rotation velocity when table tennis athletes from China serve is 69 per second. So, it is important for athletes' responding to recognize serve rotation types in advance. The Interactive Encoding Model [2] believes that there are two cognitive processes when individuals make recognition-based judgments. They firstly extract low-level relational information and temporal relationships between features, followed by high-level processing where the information extracted is judged in the context of some stored memory structure. The reason is that the stimulus is presented with an internal semantic concept, or template. Previous studies have reported the superior cognitive abilities of expert athletes, who are capable of quickly extracting important information and using this ability to identify the most relevant information by using many cognitive and motor skills [3].

Visual perception is the ability to interpret the environment by processing information contained in visible light [4], and ERP is often used to evaluate it [5]. The ERPs technique is commonly used to measure cortical activity with excellent temporal resolution, which is regarded as directly correlating to information processing. Previous studies have reported differences among expert athletes, less expert athletes and/or non-athletes. The brain characteristics of early sensory processing generally is reflected by C1 and P1 components. C1 is the very first visually evoked potential component, peaking between 40 and 80 ms post-stimulus with a midline occipito-parietal scalp distribution [6]. It is generally considered to reflect the initial activation of the primary visual cortex. Early studies failed to find the attentional modulation of C1, but recent work has suggested otherwise. Several recent C1 studies have shown that C1 might be modulated by an endogenous process, such as attention [7,8]. Jin et al. (2010) [9] asked professional badminton players to watch video clips related to their training experience and predict where the ball would land and examined whether they differed from non-player controls in the elicited C1. The results showed that C1 latency was comparable across the two groups, but its amplitude was significantly larger for the players than for the non-players. Additionally, several researchers had examined ERPs evoked by the imperative stimuli to assess visual attention. More specifically, the P1 component, a positive deflection, appeared approximately 80–150 ms after stimulus presentation. Feng et al. (2010) [10] indicated that the mean amplitudes of P1 evoked at the anterior scalp of elite fencing athletes are higher. Zhao and Zhou (2010) [11] found that elite Sanda athletes exhibited a greater P1 amplitude in a shorter latency than novices when they recognized picture stimuli and decided “attack” or “defensive”. The P1 reflects both the obligatory processing of exogenous stimulus characteristics and the earliest stages of attention [12]. The above results showed that the level of elite athletes’ nerve activity of P1 were higher in comparison with general athletes or novices.

In the phase of recognizing stimuli structure or pattern, N1 and P3 components reflected this processing. The N1 component, a negative deflection, appeared approximately 90–160 ms after the stimulus. Wang (2013) [13] found table tennis athletes (qualified as National Players at the Second Grade) had a greater amplitude of the N1 component than novices when they viewed serve clips and judged the serve types of table tennis. N1 indexed the exogenous orienting of attention and was likely to represent the activity of frontal and parietal components of the attention network involved in eliciting attention changes, and the N1 component evoked at frontal region could reflect discrimination processing in the focus of attention [14]. Of the P3 component, the greatest positive wave was elicited approximately 300–500 ms after the stimulus. Research has discovered the most differences between athletes and non-athletes groups in the amplitude and latency of the P3 component. Radlo et al. (2001) [15] found that intermediate batters produced shorter P3 latencies and larger P3 amplitudes than the advanced batters when they were asked to judge the type of baseball pitch thrown (fastball or curveball). Similarly, Taliep et al. (2008) [16] asked participants to judge the pitch type of cricket (fast or slow ball) and found a significantly reduced P3 latency in skilled cricket batsmen compared with less-skilled batsmen. The latency of the P3 marked the time needed for such processes as stimulus discrimination, pattern recognition, classification and memory template matching to occur. The amplitude of the P3 was related to many factors such as subjective probability, stimulus discriminability, task demands and stimulus meaning.

To sum up, previous studies revealed the differences between expert athletes, less expert athletes and/or non-athletes when they recognized the types of sport technique (e.g., serves or pitches), but the results appeared to be inconsistent. The reason probably was that the natural features of these motions were not presented to participants, who used very different cognitive processing strategies in the judgments-perceptual task. So, 3D pictures composed of a white ball and a hitting location (black shade point) were made by using 3ds Max 2012 software in the current study. The participants were asked to judge the serve type of table tennis according to the point of force in the kinematics principle. The aim was to reveal the athletes’ internal representation form for sport technique, the characteristics of pattern-recognition processing and neural mechanisms such as activated specific regions and levels of the cerebral cortex.

2. Methods

2.1. Participants

Fifteen male advanced table tennis athletes (mean age = 21.2, SD = 0.8) and fifteen male intermediate level table tennis athletes (mean age =20.6, SD = 1.1) were recruited in this study with informed consent, each receiving monetary compensation for 100 RMB. All of them were right-handed, with normal or corrected–to–normal vision and normal color vision. None of them had any neurological or psychiatric disorders or used any neuroleptics.

Advanced table tennis athletes from the Shanghai University of Sport's current table tennis team were qualified as National Players at the Second Grade. Their professional training experience was 7.8 $\pm$ 2.3 years with practicing more than three times a week for 2 or more hours in the last 8 years. Intermediate-level table tennis athletes from Shanghai University of Sport undergraduates were matched with the advanced athletes in age and education, and practiced table tennis less than two times a week for 1.5 h in the last 2 years. Further, none of them were qualified as any grade national players or participated any table tennis games.

2.2. Materials

Eight monochrome 3D pictures (resolution: 1360 $\times$ 768) composed of a white ball and hitting location (black shade point) were made by using 3ds Max 2012 software. Black shade points located in 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315° and 360° on the white balls implied the hitting location when the opponents were serving. The 25% frequency stimuli representing side-backspin serves and other 75% frequency stimuli representing non-side-backspin serves are illustrated in Figure 1. Infrequent pictures as target stimuli and frequent pictures as standard stimuli were, respectively, randomly presented 60 times and 180 times for a total of 240 times.

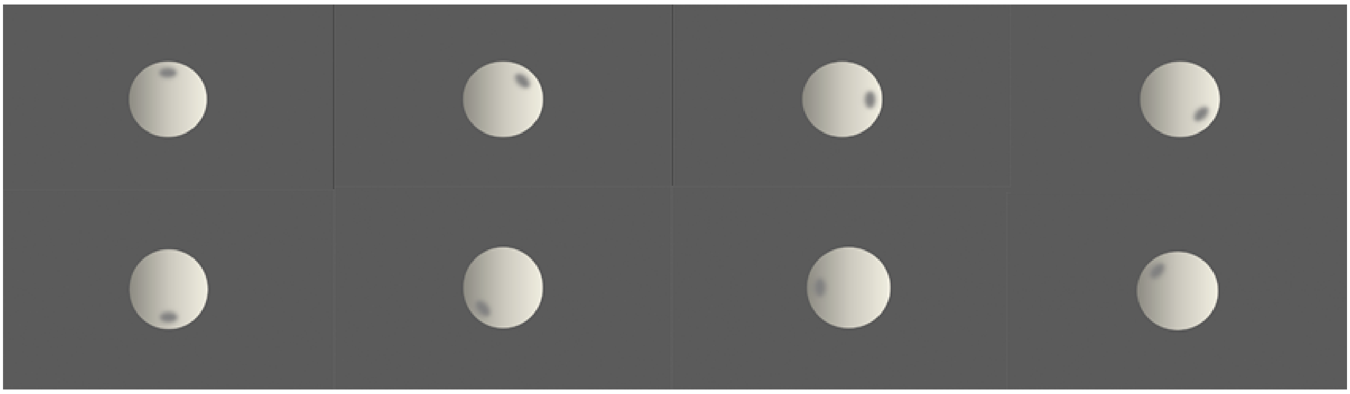

Figure 1. Three-dimensional table tennis ball pictures including hitting locations illustrating stimuli were used in the experiment. The fourth picture of the top and the second picture of the bottom were consistently estimated as possible side-backspin serves by two table tennis coaches and athletes.

All stimuli were presented at the center of a 19-inch Lenovo screen. The screen background was gray–black. Three blocks of stimuli were presented, with 80 trials in each block, and each trial was consisted of one match picture. The horizontal visual angle was 15.7°, and the vertical visual angle was 9.5°.

2.3. Procedure

Participants were individually seated in a dimly illuminated and sound-attenuated room. At first, they were told about the nature of the task and then seated in a comfortable armchair 1.5 m away from a computer screen. They were instructed to avoid head movement and eye blinks to the best of their abilities especially when picture stimuli were presented.

Figure 2 illustrated a sample trial started with a white fixation cross at the center of the screen for 500 ms, followed by a picture displayed for one of the eight pictures randomly for 800 ms and a blank for 1500 ms. The task of participants was to identify as quickly and accurately as possible whether the current picture could represent a side-backspin serve or not. They were instructed to press the "Enter" key in the keyboard with their right/left thumb finger if their answer was "yes"; if not, none of any keys would be pressed. Handedness was counterbalanced by half of the participants using their right hand to press and another half using their left. Each trial was presented by E-Prime2.0 software; at the same time, behavioral data (reaction time and accuracy rate) was recorded.

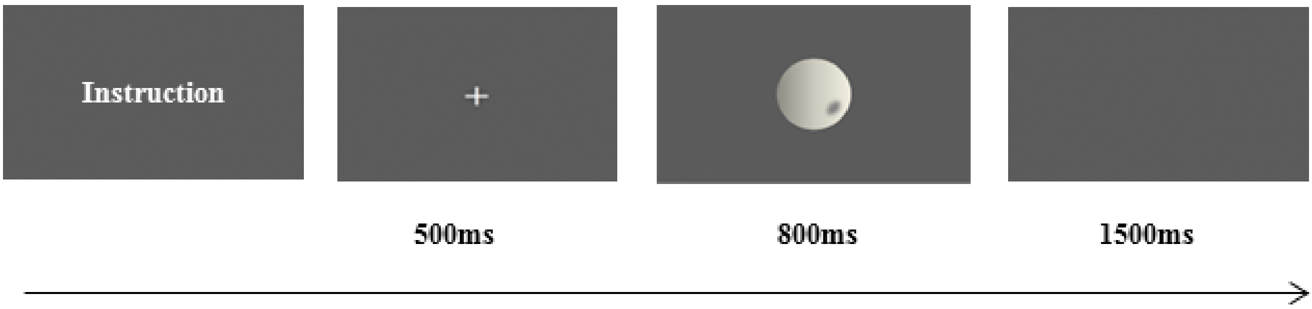

Figure 2. This is a flow-process diagram for a sample trial; when the 3D picture composed of white ball and hitting location (black shade point) appeared, the participants were instructed to identify as quickly and accurately as possible whether the current picture could represent a side-backspin serve or not and press the "Enter" key in the keyboard or not.

2.4. Electrophysiological Recording and Analysis

A continuous EEG was recorded from 64 Ag/AgCl electrodes using Brain Products from Germany at a sampling rate of 1000 Hz (high-pass filter = 0.01 Hz, low-pass filter = 100 Hz, impedances kept below 5 kΩ). The majority of electrodes were embedded in an elastic cap and arranged according to the standard 10–20 system.

Blinks, eye movement and electromyography artifacts were removed from the EEG signals. EEG epochs were extracted between 200 ms before and 1000 ms after the onset of each experimental stimulus. The TP9/TP10 average of bilateral mastoid electrodes was a new reference; then, eye movement and other artifacts were automatically corrected with amplifier saturation or EEG activity in any channel exceeding $\pm$80 μv, and a 24 Hz low-pass filter was applied before averaging.

2.5. Statistical Analyses

Behavioral data (reaction time and accuracy rate) and ERP data (peak latency and amplitude of components) were statistically analyzed by SPSS19.0 software. Greenhouse–Geisser corrections were applied for the interactive and main effects when the sphericity of variances between the groups could not be assumed, with corrected degrees of freedom reported. Simple effects were analyzed by post hoc comparisons using LSD. The significant alpha level for all analyses was 0.05.

3. Results

3.1. Behavioral Results

The reaction time (RT) to target stimuli was analyzed by an independent-samples *t* test; the results showed significant differences between groups (t (28) = −2.644, $p = 0.013 < 0.05$) in Table 1. Table tennis athletes recognized the types of serves more quickly than undergraduates. The accuracy rate (ACC) to target stimuli and standard stimuli was analyzed by independent samples' nonparametric tests (Mann–Whitney U tests), and the results showed significant differences between groups (Z (15) = −3.325, $p = 0.001$; Z (15) = −1.080, $p = 0.29 < 0.05$) in Table 1. Table tennis athletes recognized the type of serves more accurately than undergraduates.

Table 1. Behavioral results for target stimuli and standard stimuli: reaction time and accuracy rate of both table tennis athletes and undergraduates.

Groups	N	Target Stimuli (M ± SD)		Standard Stimuli (M ± SD)	
		RT (ms)	ACC (%)	RT (ms)	ACC (%)
Table tennis athletes	15	461.225 ± 40.099	98.3 ± 2.1	/	93 ± 7.7
Undergraduates	15	507.875 ± 55.307	77.8 ± 15.1	/	79.1 ± 19.4

3.2. ERPs Results

Waveforms and topography maps are shown in Figures 3 and 4, respectively. The electrophysiological components including C1 (40–80 ms), P1 (80–150 ms), N1 (90–160 ms) and P3 (300–500 ms) were induced in different brain regions when participants recognized the types of serves.

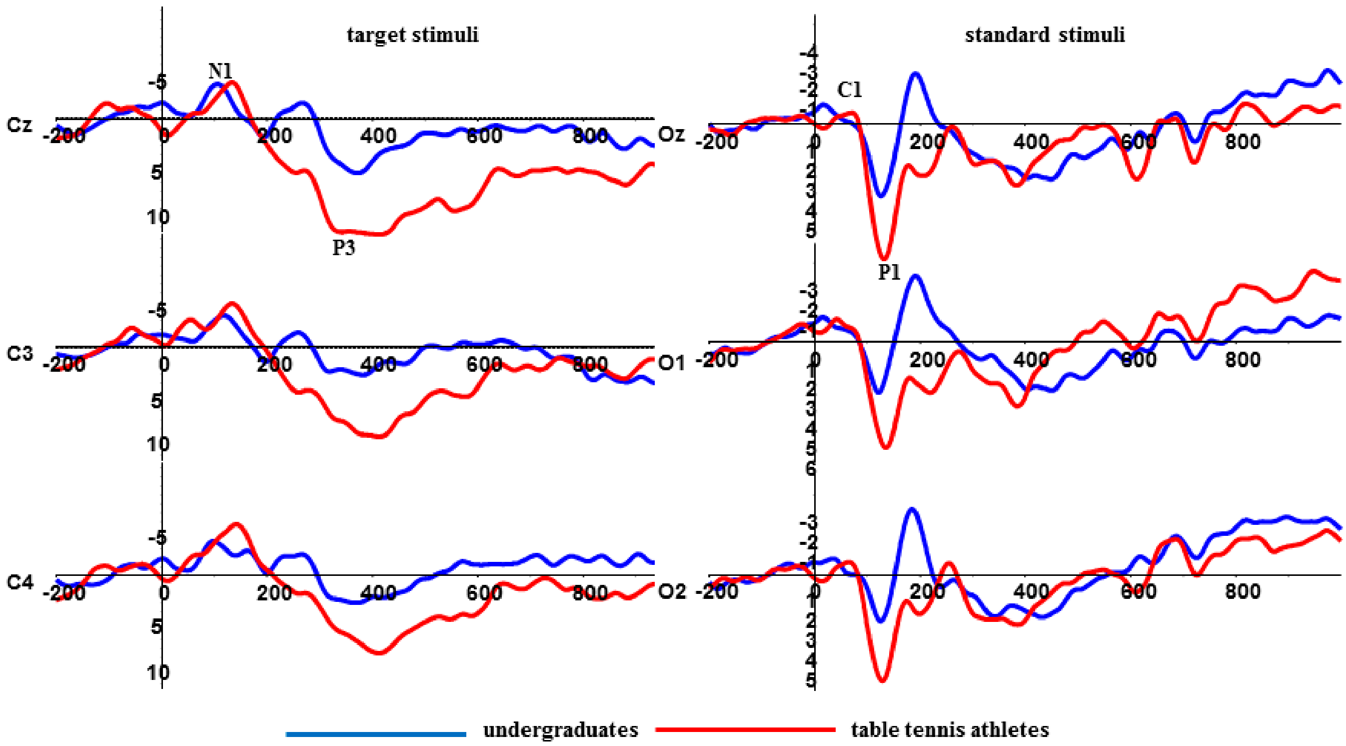

Figure 3. Grand average waveforms for correct responses of the two groups of participants. They were instructed to press a button whenever an infrequent target stimulus appeared in a series of frequent standard stimuli. The left waveforms of central sites (Cz, C3 and C4) were indexed by the responses to target stimuli, while the right of occipital sites (Oz, O1 and O2) were by standard stimuli.

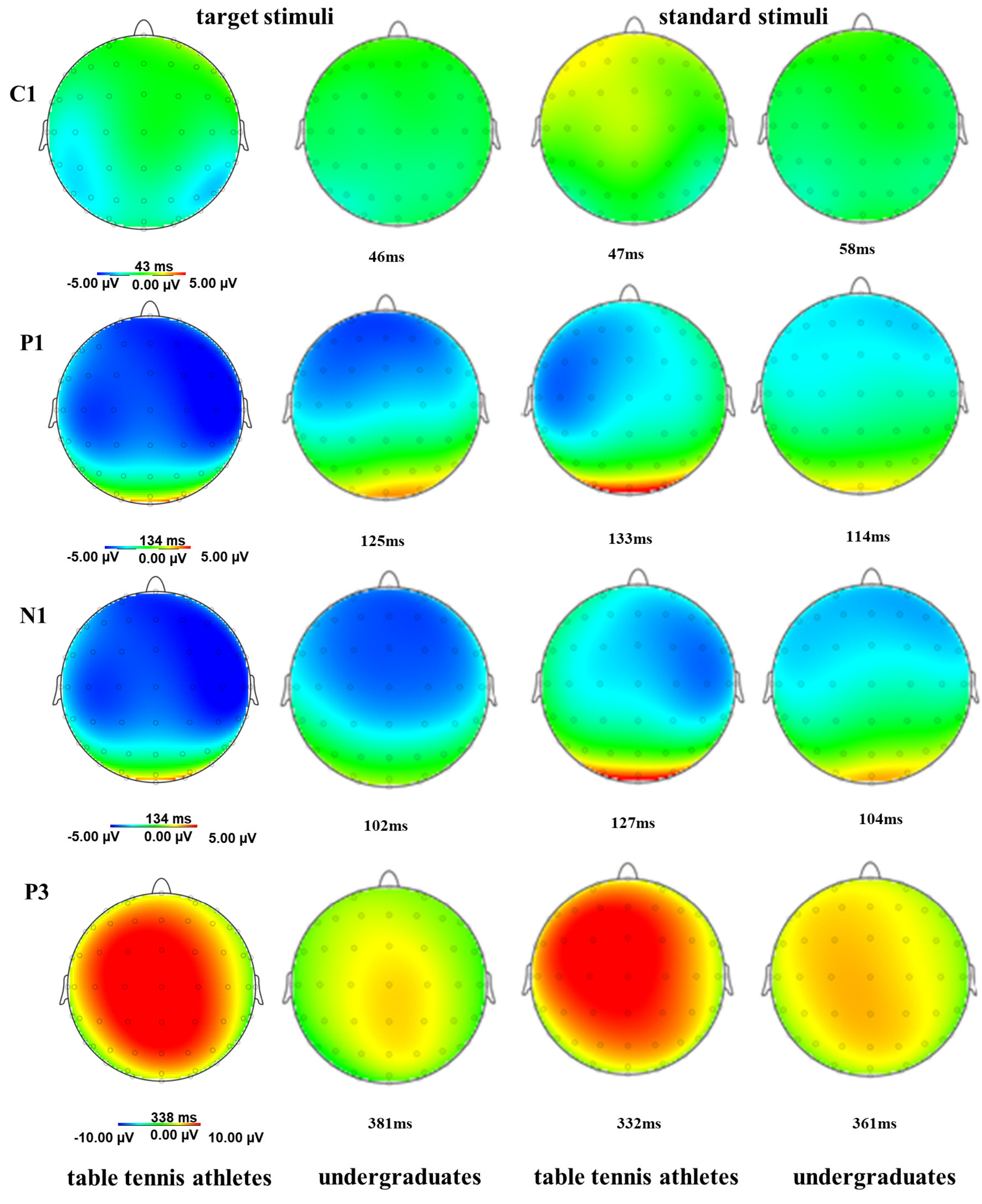

Figure 4. Scalp topographies distributions from the two groups of participants were illustrated by the mean C1, P1, N1 and P3 amplitude and latency. The distinct patterns from each component separately evoked by target stimuli and standard stimuli at the peak time point were noted. Color bar indicates mean signal amplitude in microvolts.

C1 (window from 40 to 80 ms): The peak latency and amplitude of C1 were analyzed at occipital sites (Oz, O1 and O2) in a 2 (groups) × 2 (stimuli) × 3 (electrodes) repeated-measures ANOVA. The results indicated a significant groups × stimuli × electrodes interaction (F (3.315, 92.809) = 6.334, p = 0.000, ηp2 = 0.184; F (3.484, 97.546) = 3.550, p = 0.013 < 0.05, ηp2 = 0.113). Significant differences for standard stimuli between groups were found by simple effects analysis, and the results revealed that table tennis athletes

(48.8 ms, −2.368 µv) showed a shorter C1 peak latency and larger amplitude than undergraduates (62.4 ms, −1.202 µv).

P1 (window from 80 to 150 ms): Peak latency and amplitude of P1 were analyzed at occipital sites (Oz, O1 and O2) in a 2 (groups) × 2 (stimuli) × 3 (electrodes) repeated-measures ANOVA. The results indicated a significant groups × stimuli × electrodes interaction (F (4.128, 115.577) = 6.334, p = 0.000, ηp2 = 0.248; F (2.717, 76.081) = 3.848, $p = 0.015 < 0.05$, ηp2 = 0.121). Significant differences for standard stimuli between groups were found by simple effects analyses; the results revealed that table tennis athletes (130.0 ms, 5.617 µv) showed a longer P1 peak latency and larger amplitude than undergraduates (115.2 ms, 3.536 µv).

N1 (window from 90 to 160 ms): Peak latency and amplitude of P1 were analyzed at central sites (Cz, C3 and C4) in a 2 (groups) × 2 (stimuli) × 3 (electrodes) repeated-measures ANOVA. The results indicated a significant groups × stimuli × electrodes interaction (F (2.997, 83.922) = 5.702, p = 0.001, ηp2 = 0.169; F (3.069, 85.935) = 4.441, $p = 0.006 < 0.01$, ηp2 = 0.137). Significant differences for target stimuli between groups were found by simple effects analysis, and the results revealed that table tennis athletes (127.8 ms, −6.232 µv) showed a longer N1 peak latency and larger amplitude than undergraduates (102.0 ms, −3.494 µv).

P3 (window from 300 to 500 ms): Peak latency and amplitude of P3 were analyzed at central sites (Cz, C3 and C4) in a 2 (groups) ×2 (stimuli) × 3 (electrodes) repeated-measures ANOVA. The results of peak latency indicated a significant main effect for groups (F (1, 28) = 24.174, p = 0.000, ηp2 = 0.463). Significant differences for target stimuli between groups were found by post hoc comparisons using LSD, and the results revealed that table tennis athletes (359.2 ms) showed a shorter P3 peak latency than undergraduates (418.8 ms). The results of peak amplitude indicated a groups × stimuli ×electrodes interaction (F (2.062, 57.743) = 4.226, $p = 0.016 < 0.05$, ηp2 = 0.174). Significant differences for target stimuli between groups were found by simple effects analyses, and the results revealed that table tennis athletes (15.898 µv) showed a larger P3 peak amplitude than undergraduates (7.576 µv).

4. Discussion

We hypothesized that table tennis athletes and undergraduates would show differences in performance and ERPs components during recognizing the type of serves.

In agreement with our predictions, table tennis athletes were quicker and/or more accurate than undergraduates when they recognized the type of serves by hitting location. Table tennis athletes probably developed more elaborate domain-specific knowledge structures or patterns to rapidly encode information in their memories through many hours of practice and match play [17]. Our results indicated that table tennis players can use key information to make accurate judgments.

For the table tennis athletes group, the ERPs results clearly showed an early negative component around 45–65 ms post-standard stimulus at the occipital region of the scalp topography. This component was named the C1 component in previous studies [18]. Compared with the undergraduates' group, table tennis athletes had an earlier latency and greater amplitude of the C1 component. This component reflected the early activity of the primary visual cortex (V1) for very early sensory processing. The current study probably revealed that the C1 component is modulated by long-term practice and match play; in particular, for speed-ball games such as table tennis, athletes were highly demanded in visual perceptual processing. A recent find proposed that the experience-induced brain plasticity in the primary visual cortex results in a greater C1 component for badminton players [9]. The present study showed that table tennis athletes were very sensitive to domain-specific knowledge structures or patterns (e.g., hitting location), and the greater C1 component appeared in the primary visual cortex for very early sensory processing.

Another positive component was indexed at the occipital region of scalp topographies for two groups by standard stimuli, whose time window was from 80 to 150 ms. This component was interpreted as P1 and was connected with the location of visual spatial selective attention. According to the selective attention theory, the attention to the location of objects plays an important role in the early stage of perceptual coding, which avails to recognizing the objects' characteristics [19]. Compared with the undergraduates group, table tennis athletes had a later latency and greater amplitude of the P1 component. The previous study found that individuals can voluntarily allocate significant amounts of attention to particular locations in the visual field while fixating on a central focal point [20]. Another study believed that the strengthened P1 could be related to the auto-processing of attention orientation caused by suddenly appearing visual events [21]. Özmerdivenli et al. (2005) [22] found the differences in P1 amplitude between volleyball players and non-players. The current result showed that table tennis athletes had devoted more attention for the early visual processing of the location of objects.

Around 90–160 ms post-target stimulus at central sites (e.g., Cz, C3 and C4), a clearly negative component was evoked, which was called N1. According to the previous research results, table tennis athletes' greater N1 component maybe reflect the discrimination processing of attention focusing on features of target stimuli [23]. These results were in line with previous studies on N1 elicited by recognizing motion pattern [13]. The researchers generally believed that the more time devoted in the stage of visual working memory coding and retention, the more elaborately the current processing was made. The current results showed that table tennis athletes could distribute more attention resources to prepare for the later elaborate processing and accurate recognizing.

The most noticeable difference between the ERPs profiles of table tennis athletes and undergraduates was in their P3 component changes around 300–500 ms post-target stimulus at central sites (e.g., Cz, C3 and C4). Table tennis athletes exhibited a greater P3 amplitude in a shorter latency than undergraduates. The P3 latency could reflect the time used to evaluate and classify stimuli [24], while the P3 amplitude could be used to index the demands on a person's attention-capacity resources [25]. It seemed that table tennis athletes could accurately recognize the type of serves earlier by allocating more limited attention-capacity resources in rapid perceptual decision-making tasks such as studied in the present study. The reason could be due to their extensive experience in viewing the type of serves to help them more effectively match visual information about serves to structures or patterns stored in the long-term memory. Some similar results were found by comparing P3 characteristics between athletes and non-athletes [26–28]. Important results were obtained in the current study, but some limitations remain. Firstly, the sample size was not large enough, which limited the robustness of the results. Secondly, this study was cross-sectional and could not confirm the exact origin of the differences between the two groups.

5. Conclusions

In summary, the current study compared the ERPs characteristics between table tennis athletes and undergraduates in completing perceptual decision-making tasks. The results showed that table tennis athletes responded more quickly and accurately; there were obviously differences in the whole brain's activated order and level between the advanced and intermediate level male table tennis athletes; and C1and P1 components were induced in the occipital region, N1 in the central region and P3 in every region. For table tennis athletes, in the phase of early sensory processing for stimuli features (such as hitting location), the cerebral cortex was activated at a higher level in comparison with undergraduates, and athletes' brain plasticity probably developed because of long-term exercise training, making them very sensitive to physical features of relevant movement stimuli; in the phase of recognizing stimuli structure or patterns, the cerebral cortex was also more activated, with a faster recognizing speed, and more mental resources were devoted. Athletes' extensive experience in viewing serve types is significant. It can help them more effectively match the visual information of serves with the structures or patterns stored in their long-term memory.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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