Neural Mechanisms of Intuitive Tactical Decision-making
Predominance of High-level Fencing Athletes

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Abstract

Intuitive decision-making is a typical form of thinking in sports situation. The purpose of the study was to explore the neural mechanisms of tactical intuition predominance of elite fencing athletes. This study selected 39 subjects, including elite fencing athletes (N = 8), level-1 fencing athletes (N = 14), level-2 fencing athletes (N = 11) and non-level fencing athletes (N = 6). Event-related potential (ERP) recording was collected to compare between different level of fencing athletes. According to the operational standards of sports intuition, the responses of elite, level-1 and level-2 fencing athletes belonged to intuitive decision-making and that of non-level fencing athletes belonged to random guessing. ERP data showed that the mean amplitude of P1 and peak amplitude of P3, positives slow wave (PSW) of elite fencing athletes were higher than those of general (level-1 and level-2) fencing athletes. The peak latency of PSW was shorter than that of general fencing athletes at relevant cerebral cortex regions during the process of intuitive tactical decision-making. The results indicated that the tactical decision-making strategy of elite fencing athletes mainly aimed at the accuracy. Their anticipating speed was faster than the other general sport activities (1500 ms). The pointing focus degree of exogenous attention and the updating degree of mental token of judging tactics intention were higher. The neural mechanisms of performance predominance maybe the nerve activity levels of P1, P3 and PSW evoked at the special cerebral cortex being higher and the evoked time of P3 and PSW being earlier.

Keywords: Fencing, Intuitive decision-making, Predominance, Neural mechanism, Event-related potential (ERP)

1. Introduction

Competitive sports is a special kind of exercise, in which the movement of each performer is completed by command of his brain, the decision-making center of performance behavior. For those more complicated sports items, the effects of thinking in decision-making have direct impact on the performance and the outcomes. Because the complicated sports situation has the characteristics of rapid movement, high pressure of time, and uncertain outcomes, athletes often carry out intuitive decision-making in competition and complement by analytical decision-making, or called cognitive decision-making.

Early studies of intuitive tactical decision-making were generally based on the assumption that the visual and physical system of an expert is better than that of a novice [1-4]. The indexes adopted in these studies were static and dynamic visual acuity, depth perception, color discriminability, peripheral vision etc. Although the research results were not consistent, there were still a few studies which confirmed the above assumptions. This formed the concept of a “hardware” faction about the sports expert predominance. It is thought that sports experts have better visual physical hardware [1,2]. Williams et al. [3] thought that the theory of experts’ cognitive predominance of hardware was suspect. Williams et al. [4] also proved that the physical properties of visual system had definite effects on motor skills; meanwhile, the article did not show a high correlation with motor skills. Because of the divarication in studies results, the opinion of hardware faction caused a number of arguments.

As the opinion of “hardware” faction lacks the support of experimental evidence, more and more studies have turned their research direction to experts’ “software” characteristics of information processing. Previous results showed that the predominance of experts was derived from more focused attention, more political searching and more effective recognition, analysis, translation and edition on visual information [5]. Generally speaking, researchers consistently agree that main predominance of expert cognition was in the following areas: (1) the use of highly efficient visual searching strategies and the early visual clues to better predict the movement intentions of opponents [6-8]; (2) recalling and recognizing complex movement patterns quickly and accurately [9]; (3) being able to quickly and accurately detect the relevant movement mains from a complex background of
movement [10]; and (4) anticipating accurately the upcoming events in certain scenes [11]. The findings are basically similar to empirical studies by Wang [12], who conducted some experiments to explore the cognitive characteristics of baseball players, handball players and badminton players from the angle of sports intuition or sports thinking.

The opinions of sports experts have a broad consensus on specialty cognition predominance, but a unified point of view on the formation mechanism of cognitive predominance. Different factions put forward a variety of hypotheses from different perspectives, such as the transcendental theory, the experience theory and the meta-cognitive theory. Among them, the experience theory has received more support in the literature [13]. Acquired knowledge and experience are the main factors influencing the formation of expert cognitive predominance. Meanwhile, some investigators also thought that choosing and using different strategies could also be attributed to knowledge experience, actually.

Studies of sports intuition are few, mainly focused on theoretical exploration and ignoring empirical study, which is related to a lack of appropriate research methods and applied techniques. The specificity for sport cannot be traced by many experimental contexts and methods of psychology, which also makes empirical studies of sports intuition in trouble. In recent years, non-invasive brain imaging technology widely used, especially the event-related potentials (ERP) with high temporal resolution [14], can likely reveal the neural mechanism of performance predominance of sports experts.

Fencing is a combat sport of high antagonism and competitive impetuosity, which has a good reputation for match of speed and wisdom [15]. With its fast and frequent attack and defense, fleeting match opportunities and daedal match situation, athletes must make accurate and efficient judgment, fast and flexible decision-making according to the variety of their opponents and match fields in a very short time. Although research has well indicated that differences between the expert and novice athletes exist in special perception abilities and the cognitive process of visual searching, perceptual anticipation and sports decision-making [6-12], studies on the neural mechanisms of cognitive predominant characteristics of expert athletes are few due to the restrictive conditions of experimental situation and techniques at present.

In addition, ERP studies comparing males with females found that the amplitude of females was slightly higher than that of males; the latency of females was a little shorter than that of males, but the differences had no significance [14]. Moreover, Mullis et al. [16] reported that the latency of visual P300 of females was noticeably shorter than that of males. The gender may be one of factors which effects on the amplitude and latency of ERPs.

To sum up, with the theoretical guidance of acquired experience theory of cognitive predominance of sports experts, the purpose of this study was to tentatively explore the characteristics and its possible neural mechanism of tactical intuition predominance, which determines the performance and outcomes of high-level fencing athletes. In the current experiment, it was assumed that the processes of tactical decision-making of high-level fencing athletes have predominance of fast decision-making speed, high accuracy rate, high degree of updating mental tokens, much more mental operational resources occupied, etc. Its possible mechanisms were shorter changing process and higher level of nerve activity which activated specific regions of the cerebral cortex.

2. Methods

2.1 Participants

Thirty-nine fencing athletes (21 male, 18 female) on the Shanghai and Jiangsu provincial fencing team, aged 15-29 yrs (M = 19.28, SD = 3.68), voluntarily participated in this experiment. According to the skill level, which was evaluated by China Sport General Administration according to their best athletic results, all subjects were divided into four groups, in order of descent, that is, elite group, level-1 group, level-2 group and non-level group. The natural situations of athletes in each group are shown in Table 1. The elite group included 4 male and 4 female athletes; the level-1 group included 6 male and 8 female athletes; the level-2 group included 7 male and 4 female athletes; the non-level group included 4 male and 2 female athletes. Prior to taking part in this experiment, subjects provided written consent on a form approved by the institution’s human subjects review board. All subjects had normal or corrected-to-normal vision, and good health and were without brain injury and history of nervous system disease, and were each paid appropriate rewards for their participation.

2.2 Experimental setup

Recording equipment for EEG was a 64-channel ERP recording and analysis system of the German Brain Products Company. Ag/AgCl recording electrodes were fixed on an electrode cap; electrodes were oriented by the 10-20 international standard electrode system. The reference electrode was placed on the nose tip, a fronto-central electrode was used as ground. The horizontal electro-oculogram (HEOG) was monitored from electrodes at the outer canthi of the eyes, and the vertical electro-oculogram (VEOG) was monitored above and below the orbital region of the left eye. Electrode impedances did not exceed 10 kΩ. The EEG signals were recorded continuously by the amplifiers; filter bandwidth was 0.016–100 Hz, sampling frequency was 500 Hz/channel.

The experimental computers were two DELL desktop computers, with CPU frequency of 3.0 GHz; the operating system was Windows XP. Besides these two computer monitors, another computer monitor was used to show the experimental tasks. All three monitors were 19-inch flat screen, with resolution frequency of 1024 × 768 and refreshing frequency of 100 Hz.

2.3 ERP experiment

2.3.1 Stimuli

The original materials were television video of some fencing individual and team foil matches of the 2005 Fencing World Cup originally broadcast on stations in Spain, Paris,
Mechanisms of Intuitive Tactical Decision-making

Table 1. Natural situation of athletes of different group athletes (M±SD).

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Length of training (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite group</td>
<td>8</td>
<td>24.41 ± 3.38</td>
<td>179.13 ± 8.25</td>
<td>72.63 ± 10.70</td>
<td>10.63 ± 2.92</td>
</tr>
<tr>
<td>Level-1 group</td>
<td>14</td>
<td>19.86 ± 2.06</td>
<td>178.71 ± 7.41</td>
<td>67.21 ± 8.91</td>
<td>7.64 ± 1.60</td>
</tr>
<tr>
<td>Level-2 group</td>
<td>11</td>
<td>16.79 ± 1.28</td>
<td>179.00 ± 6.69</td>
<td>64.82 ± 10.26</td>
<td>5.77 ± 1.13</td>
</tr>
<tr>
<td>Non-level group</td>
<td>6</td>
<td>15.67 ± 0.51</td>
<td>180.17 ± 7.31</td>
<td>65.83 ± 5.64</td>
<td>3.93 ± 1.03</td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
<td>19.28 ± 3.68</td>
<td>179.10 ± 1.14</td>
<td>67.44 ± 1.50</td>
<td>7.16 ± 0.45</td>
</tr>
</tbody>
</table>

Figure 1. The example of 5 match pictures appeared continuously in one trial. The order in which they appeared, from (a) to (e).

Portugal, Bosnia-Herzegovina, and Venice. We used Ulead Video Studio 10.0 image editing software, based on research needs, to capture match video segments from one side to start an attack until the end of this round of confrontation. Then, we used Ulead Video Studio 10.0 again to intercept the video segment of before the offensive-side athlete had made an effective response to the offensive side attack into 5 match pictures, according to every interval of a frame. Next, we let fencing coaches and athletes to judge the tactics of the two athletes in the captured match picture and evaluate the degree of difficulty to judging. Finally, according to the consistency ratio (greater than 75%) of assessment results, the identification difficulty degree (medium), the athletes size and their location in the match picture, the interference degree of background of match picture, we selected total 120 pictures of 24 video segments as primary experimental stimuli, these pictures not only accorded with the requirements of ERP experiment but also meet to the research purposes.

We created primary experimental stimuli under unified specifications of 750 (width) × 576 (height) pixels by Batch Image Resizer software, and then adjusted the color, brightness and contrast of each picture by PhotoShop 10.0 software, in order to eliminate the influence of differences in color, brightness and contrast of each picture on ERP experiment as far as possible.

All these finally created stimuli pictures were presented on a 19-inch DELL flat screen monitor, the screen background was black. The horizontal visual angle of stimuli was 18.2°, the vertical visual angle was 14.7°. Three blocks of stimuli were presented, with 24 trials in each block. Each trial consisted of 5 match pictures (Figure 1).

2.3.2 ERP recording procedure

The ERP recording procedure was designed using E-prime software (Figure 2). Each trial procedure was as follows: subjects pressed any key to start the procedure. Firstly, the instructions “Please, according to the tactical intention of attack players in match pictures, judging tactics to be adopted by you as defending players, press “1” for defense; press “3” for counter-attack. The reaction must be fast and exact. When you are ready, press any key to start test.” appeared. Secondly, after subjects press any key, a white “+” appeared at the center of the black screen, the appearance time was 500 ms. Thirdly, a series of 5 match picture stimuli appeared continuously; the appearance time of each match picture was 80 ms and the total time was 400 ms. Fourthly, black screen was maintained for 1500 ms. During the appearance of match pictures (400 ms) and subsequent 1500 ms black-screen, participants had to press key quickly and exactly according the types of tactical decision-making. If participants made no any responses or press tightly during above time, it was regard as wrong response. The time interval between response finish and next appearance of white “+” was 1500–2300 ms randomly. Thus, the experimental circulation was like the above trial procedure. Subjects were informed to respond speedily and accurately at the same time. The experiment was a task of one choice of two; the two choices were defense and counterattack, the relative likelihood of defense and counterattack was 2 to 1.

2.3.3 Experimental process

Before participants were led into the ERP lab with sound-attenuated and light-insulation, they had to be familiar
with the lab environment and fill out a test questionnaire. Subsequently, each participant was seated 60 cm from the screen monitor, and the center of the screen was at eye level. Their lower jaw was put into the fixation bracket at test-bed edge, in order to keep the head and body fixed during the experimental process. Then they were told to relax their whole body, especially the head and facial muscles, trying to minimize eye blinks. Later, their head was put in an electrode cap on to check impedance; meanwhile, they were given a description of the experimental task. The participants responded via a computer numeric keyboard. A practice session of 5 trials was done in order to let participants to be familiar with the response keys and the experimental program. If subject had no questions, then the test began.

2.4 Data collection and analysis

Behavioral data were collected by the software of E-prime. The variables of behavioral performance adopted in the analysis procedure were reaction time of correct responses in all trials and accuracy rate (the percentage of correct-response trials to total number of trials).

ERP data were collected by blood pressure (BP) Recorder software and were analyzed off-line by BP Analyzer software. Automated artifact rejection was performed off-line to eliminate date epochs contaminated by blinks, saccades and muscle activity and trials with EEG voltages exceeding ± 100 µV were rejected from the average. The ERP analysis epoch was 1200 ms long, starting 200 ms after the onset of each trial. The ERP signals were filtered by 0.1-16 Hz non-phase-shift digital filter and averaged for correct responses. We examined the peak latency, mean amplitude, peak amplitude of 64 electrodes on the whole scalp in order to suspend which electrodes’ activity related to predominant mechanisms of high-level fencing athletes’ intuitive tactical decision-making.

Moreover, as each tactical decision-making task in this study was presented by showing five fencing match pictures orderly and continuously to obtain the simulated video-presentation effect, the (early) process of back picture could be interfered by the process of the first picture. It was difficult to separate independently the effects of early visual ERPs, such as P1 and N1, 200ms after trial onset. Since the latency of the C1 component was assumed to be generated between 62 ms and 72 ms in the primary visual cortex and the subsequent P1 and N1 were assumed between 110–130 ms and 160–190 ms, respectively, we calculated the mean amplitude in the time windows of 80–130 ms and 130–200 ms, in order to examine the differences in P1 and N1 between different groups.

For examining the differences between groups in behavior responses and ERP data, a multivariate analysis of variance (MANOVA) having the accuracy rate, the RT and peak latency, mean amplitude, peak amplitude as dependent variables, having the independent factors of athletic level (elite, level.1, level.2) and gender (female, male) were performed. An alpha level of 0.05 was used as significance level. LSD was used for post hoc test comparisons ($p < 0.05$).

3. Results

3.1 Behavioral data

The behavioral data on tactical decision-making of different groups are presented in Table 2. According to previous work [17], the operational standards of sports intuition were defined as: (1) anticipation RT was less than 1500 ms and people could not finished the rigorous logic illation process: (2) anticipation accuracy rate was great than random probability: (3) complex sports situation. Table 2 shows that the accuracy rate of elite group, level.1 and level.2 group were all above 60 percent, higher than random probability (50%), but the accuracy rate of the non-level group was about 51.69 percent, almost equal to random probability. These results indicated that the process of tactical decision-making of elite, level-1 and level-2 fencing athletes belonged to intuitive decision-making and that of non-level fencing athletes did not fully belong to intuitive decision-making and was mainly composed of random guesses. Because the aim of this study was to reveal the neural mechanism of intuitive tactical decision-making predominance of high-level fencing athletes, as well as of the 3 valid participants of the non-level group left after the ERP analysis,
the study mainly analyzed the data of behavior and ERPs of the elite, level-1 and level-2 groups without the non-level group.

In addition to non-level fencing athletes, 3 × 2 (group × gender) MANOVA of RT and accuracy rate for correct responses showed that there were no significant main effects of group (accuracy rate: $F(2,33) = 0.360, p = 0.701$; RT: $F(2,33) = 0.839, p = 0.443$) and gender (accuracy rate: $F(1,33) = 0.431, p = 0.517$; RT: $F(1,33) = 0.181, p = 0.674$) and interaction of group with gender (accuracy rate: $F(2,33) = 1.314, p = 0.285$; RT: $F(2,33) = 2.595, p = 0.093$). However, it can be seen from Table 2 that the RT increased with the improvement of accuracy rate.

Table 2. Behavioral results of tactical decision-making of different group athletes.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>RT (ms) Mean</th>
<th>SD</th>
<th>Accuracy rate (%) Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite group</td>
<td>8</td>
<td>643.81</td>
<td>179.45</td>
<td>65.03</td>
<td>8.90</td>
</tr>
<tr>
<td>Level-1 group</td>
<td>14</td>
<td>535.96</td>
<td>109.93</td>
<td>60.92</td>
<td>10.39</td>
</tr>
<tr>
<td>Level-2 group</td>
<td>11</td>
<td>554.16</td>
<td>176.58</td>
<td>63.36</td>
<td>10.06</td>
</tr>
<tr>
<td>Non-level group</td>
<td>6</td>
<td>470.72</td>
<td>39.84</td>
<td>51.69</td>
<td>2.75</td>
</tr>
</tbody>
</table>

The behavior results indicated that the tactical responses belonged to intuitive reaction except in non-level fencing athletes, and there was no obvious difference between elite, level-1 and level-2 fencing athletes. Furthermore, comparing with anticipation RT of less than 1500 ms defined in the operational standards of sports intuition, the RT of fencing athletes in this study were very fast.

3.2 ERP data

Figure 3 displays grand average waveforms for the correct responses of tactical decision-making of different level fencing athletes. For illustrative purposes, the ERP components of N2, P3 and PSW showing significance results in the statistical analysis were depicted as topographical voltage maps based on all electrodes of the montage (Figure 4).

3.2.1 P1

According to previous ERP results, we adopted the mean amplitude of 80–130 ms time window to denote P1 component. The results of mean amplitude in 80–130 ms time window recording from the electrodes of Fz, FCz, Cz, CPz, Pz, Oz and POz showed that the P1 mean amplitude of POz was highest (-1.18 ± 1.02 µV), and that of FCz was lowest (-0.22 ± 1.22 µV). Table 3 displays the mean amplitude of P1 recording from the POz and FCz electrodes of different groups of athletes.

We carried out a 3 (group) × 2 (gender) MANOVA. In the 80–130 ms time window, there was a significant main effect of group at the electrodes of Fz ($F(2,33) = 5.195, p = 0.012$), F1 ($F(2,33) = 3.512, p = 0.044$), F3 ($F(2,33) = 3.978, p = 0.031$), F5 ($F(2,33) = 4.614, p = 0.019$), F7 ($F(2,33) = 3.742, p = 0.037$), F2 ($F(2,33) = 5.828, p = 0.008$), F4 ($F(2,33) = 8.320, p = 0.002$), F6 ($F(2,33) = 8.653, p = 0.001$), F8 ($F(2,33) = 8.590, p = 0.001$), FCz ($F(2,33) = 6.208, p = 0.006$), FC1 ($F(2,33) = 5.515, p = 0.010$), FC3 ($F(2,33) = 4.501, p = 0.021$), FC5 ($F(2,33) = 6.793, p = 0.004$), FC2 ($F(2,33) = 6.630, p = 0.005$), FC4 ($F(2,33) = 7.059, p = 0.003$), FC6 ($F(2,33) = 8.501, p = 0.001$), Cz ($F(2,33) = 5.381, p = 0.017$), C1 ($F(2,33) = 4.146, p = 0.027$), C3 ($F(2,33) = 4.006, p = 0.030$), C5 ($F(2,33) = 3.997, p = 0.030$), C2 ($F(2,33) = 4.491, p = 0.021$), C4 ($F(2,33) = 4.606, p = 0.019$), C6 ($F(2,33) = 4.458, p = 0.021$), and post hoc analysis showed that the mean amplitudes evoked at the anterior scalp of the elite group were higher than those of level-1 and level-2 group obviously, but no difference was observed between the level-1 and level-2 groups. Furthermore, no significant main effects of gender and interaction of group with gender were found at the above electrodes.

These results indicated that the level of nerve activity of P1 evoked at the anterior scalp of elite fencing athletes were higher in comparison with level-1 and level-2 fencing athletes.

3.2.2 N1

According to previous ERP results, we adopted the mean amplitude of 130–200 ms time window to denote N1 component. The results of mean amplitude in 130–200 ms time window recording from the electrodes of Fz, FCz, Cz, CPz, Pz, Oz and POz showed that the N1 mean amplitude of Oz was highest (2.72 ± 4.18 µV) and that of FCz was lowest (-0.98 ± 1.02 µV). Table 3 displays the mean amplitude of N1 recording from the Oz and FCz electrodes of different groups of athletes. In the 130–200 ms time window, there were no significant main effects of group and gender and interaction of group with gender at different electrodes on the whole scalp. The results indicated that no difference existed in the level of nerve activity of N1 at the whole scalp between different level fencing athletes.

3.2.3 N2

From the grand average ERP waveforms of FCz electrode for correct responses (see Fig. 3), an obvious negative ERP component could be seen during the time window of 200 to 350 ms, namely N2 which evoked when athletes carried out intuitive tactical decision-making. N2 latency was about 250 to 270 ms. The results of the peak amplitude and peak latency of N2 recording from the electrodes of Fz, FCz, Cz, CPz, Pz, Oz and POz showed that the N2 peak amplitude of FCz was highest (-8.13 ± 6.16 µV), and its peak latency was about 270 ms (272.97 ± 18.50 ms). Table 4 displays the peak latency and peak amplitude of N2 recorded from the FCz electrode of different group athletes.

Table 3. Mean amplitude of 0.130 ms and 130–200 ms time windows of different group athletes (M ± SD).

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>P1 (80–130 ms)</th>
<th>Mean</th>
<th>SD</th>
<th>N1 (130–200 ms)</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elite group</td>
<td>8</td>
<td>1.25 ± 0.71</td>
<td>0.93 ± 0.41</td>
<td>2.74 ± 1.54</td>
<td>-0.56 ± 0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level-1 group</td>
<td>14</td>
<td>1.87 ± 1.34</td>
<td>-0.76 ± 0.49</td>
<td>2.96 ± 2.34</td>
<td>-1.23 ± 1.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level-2 group</td>
<td>11</td>
<td>0.24 ± 0.26</td>
<td>-0.37 ± 0.24</td>
<td>2.39 ± 1.60</td>
<td>-0.97 ± 1.07</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MANOVA analysis of N2 showed that there were no significant main effects of group and gender and interaction of group with gender at different electrodes on the whole scalp. The results indicated that no difference existed in the level of nerve activity of N2 on the whole scalp between different level fencing athletes.
Figure 3. Grand average waveforms for correct responses of tactics decision-making of fencing athletes of different groups. Top: grand average waveforms refer to electrode FCz. Bottom: grand average waveforms refer to electrode Pz.

3.2.4 P3

From the grand average ERP waveforms of Pz electrode for correct responses (see Fig. 3), an obvious positive ERP component could be seen at about 300 ms, namely P3, which was evoked when athletes made tactical decisions. Measuring the peak amplitude and peak latency of P3 at the recording electrodes of Fz, FCz, Cz, CPz, Pz, Oz and POz, the results showed that for the highest amplitude of P3 at the recording electrode of POz (10.31 ± 5.37 µV), its latency was about 300 ms (293.21 ± 31.90 ms). Table 4 shows the peak latency and peak amplitude of P3 recorded from the POz electrode of different group athletes.

Table 4. Peak latency and peak amplitude of N2, P3 and PSW of different group athletes (M ± SD).

<table>
<thead>
<tr>
<th></th>
<th>Elite group</th>
<th>Level-1 group</th>
<th>Level-2 group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peak latency</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N2 (FCz)</td>
<td>274.00 ± 25.77</td>
<td>273.00 ± 14.40</td>
<td>274.36 ± 22.92</td>
</tr>
<tr>
<td>P3 (POz)</td>
<td>316.50 ± 42.41</td>
<td>327.00 ± 58.62</td>
<td>315.33 ± 46.44</td>
</tr>
<tr>
<td>PSW (Cz)</td>
<td>386.50 ± 59.32</td>
<td>422.77 ± 70.31</td>
<td>395.83 ± 89.25</td>
</tr>
<tr>
<td>PSW (Pz)</td>
<td>386.00 ± 53.37</td>
<td>390.92 ± 51.93</td>
<td>389.00 ± 82.89</td>
</tr>
<tr>
<td><strong>Peak amplitude</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N2 (FCz)</td>
<td>-7.84 ± 2.03</td>
<td>-8.74 ± 0.98</td>
<td>-9.81 ± 2.63</td>
</tr>
<tr>
<td>P3 (POz)</td>
<td>13.41 ± 6.25</td>
<td>9.32 ± 3.75</td>
<td>12.43 ± 3.70</td>
</tr>
<tr>
<td>PSW (Cz)</td>
<td>6.43 ± 3.37</td>
<td>2.73 ± 1.51</td>
<td>5.96 ± 3.73</td>
</tr>
<tr>
<td>PSW (Pz)</td>
<td>12.36 ± 6.48</td>
<td>7.31 ± 3.94</td>
<td>10.26 ± 4.22</td>
</tr>
</tbody>
</table>

MANOVA analysis of P3 peak latency demonstrated no significant main effects of group and gender and interaction of group with gender at the whole cerebral cortex were observed.

MANOVA analysis of P3 peak amplitude presented that there was significant main effect of gender at the electrodes of Fz ($F(1,33) = 11.088, p = 0.003$), FCz ($F(1,33) = 8.294, p = 0.008$), Fpz ($F(1,33) = 8.733, p = 0.006$), AF3 ($F(1,33) = 8.000, p = 0.009$), AF4 ($F(1,33) = 6.686, p = 0.015$), F3 ($F(1,33) = 10.047, p = 0.004$), F5 ($F(1,33) = 6.825, p = 0.015$), FC3 ($F(1,33) = 10.211, p = 0.004$), FC4 ($F(1,33) = 7.982, p = 0.009$), and had no significant group main effect and interaction of group with gender.

t-test analysis showed that the P3 peak amplitude of male fencing athletes was higher than that of female fencing athletes. Moreover, there was significant group main effect at the electrodes of AF8 ($F(2,33) = 4.584, p = 0.019$), F8 ($F(2,33) = 4.256, p = 0.025$), FT8 ($F(2,33) = 5.327, p = 0.011$) and C6 ($F(2,33) = 4.652, p = 0.018$). Post hoc analysis showed that the P3 peak amplitude of the elite group and level-2 group were higher than that of the level-1 group, and there was no significant difference between elite group and level-2 group.

The results indicated that the level of nerve activity of P3 evoked at specific regions of cerebral cortex of elite and level-2 fencing athletes were higher by comparison with that of the level-1 fencing athletes.
3.2.5 PSW

From the grand average ERP waveforms of FCz and Pz electrodes for correct responses (see Figure 3), a positive slow wave could be seen at about 470 ms and 370 ms, namely PSW, which was evoked after P3 component. The PSW peak latency was about 390–420 ms at the anterior part of brain scalp and the highest amplitude of PSW at the recording electrode of Cz (4.80 ± 5.38 µV); the PSW peak latency was about 380–390 ms at the middle and posterior parts of the brain scalp, the highest amplitude of PSW at the recording electrode of Pz (9.60 ± 6.64 µV). Table 4 displays the peak latency and peak amplitude of PSW recorded from the Cz and Pz electrodes of different groups of athletes.

MANOVA analysis of PSW peak latency showed that there was significant main effect of group at the electrodes of AF3 (F(2,33) = 3.677, p = 0.039), AF7 (F(2, 33) = 3.695, p = 0.038), F5 (F(2,33) = 3.455, p = 0.046), F7 (F(2,33) = 3.447, p = 0.046). Post hoc analysis showed that the peak latency of PSW evoked at the left prefrontal and frontal-central region of the level-1 group was longer than that of the elite group, and there was no obvious difference between the level-1 and level-2 groups. Moreover, a significant main effect of gender was observed at the electrodes of CP4 (F(1, 33) = 4.187, p = 0.050), P4 (F(1, 33) = 5.730, p = 0.024), P8 (F(1,33) = 4.524, p = 0.043), POz (F(1,33) = 4.486, p = 0.044), PO4 (F(1,33) = 4.817, p = 0.037), PO8 (F(1,33) = 5.398, p = 0.028), Oz (F(1,33) = 6.965, p = 0.014), O1 (F(1,33) = 5.818, p = 0.023), O2 (F(1,33) = 7.832, p = 0.009). t-test analysis showed that PSW peak latency of male fencing athletes was shorter than that of female fencing athletes.

MANOVA analysis of PSW peak amplitude showed that there was significant group main effect at the recording electrode of FT8 (F(2,33) = 3.533, p = 0.043) and C4 (F(2,33) = 3.398, p = 0.048), and no significant main effects of gender and interaction of group with gender. Post hoc analysis showed that the peak amplitude of PSW evoked within the right temple-frontal lobe region (F8, FT8, T8), right central region (C2, C4, C6) and right central-parietal region (CPz, CP1, CP2, CP4) of the elite and level-2 groups were obviously higher than that of the level-1 group, but there were no obvious differences between the elite group and level-2 group.

The results indicated that the time-evoked PSW at specific regions of cerebral cortex of elite fencing athletes was earlier, and the level of nerve activity of PSW was lower by comparison with the level-1 and level-2 fencing athletes. Furthermore, the time-evoked PSW of male athletes was shorter than that of female athletes.

4. Discussion

4.1 Strategy of intuitive tactical decision-making

The behavior results showed the accuracy rate of intuitive tactical decision-making of high-level athletes was slightly better than that of general ones; the speed of decision-making was much slower than that of general ones. These results were consistent with findings of [18] which conducted experimental research on anticipation ability of badminton athletes through combining methods of image frame technology and oral report. The results showed the accuracy rate of professional badminton athletes to anticipate the falling point was significantly higher than that of non-professional badminton students when the opponent hit the ball, and the anticipating RT was significantly longer than that of non-professional badminton students. These indicated that the accuracy rate of anticipation is closely related with levels of movement, but there was no correlation between anticipating RT with levels of movement.

Based on summarizing the laboratory and field research, Ripoll [19] put forward a general model of information processing in complex sport situations and pointed out that there...
had two different visual functions in movement. One is semantic visual function; its function is to identify and explain the scene. The other is sensual-sport visual function; its function is to execute reaction. If the athletes emphasize understanding the sport situations and being aware of semantic information (what are cues of sport scene? and where and when will the cues appear?), they will give priority to veracity and tend to make correct decisions, so these kind of decisions are safe correspondingly. If the athletes emphasize grasping sensual sport information and being aware of how to do activities, they will give priority to speed and tend to make fast decisions, so this kind of decision will have a certain degree of risk. In the sport situation, the problems which all athletes will face is seeking a kind of decision will have a certain degree of risk. In the sport situations and being aware of semantic information (what are cues of sport scene? and where and when will the cues appear?)

The other is sensual-sport visual function; its function is to identify and explain the scene. An ERP study conducted by McPherson studied the problem token of tennis experts-novices by using the method of verbal report, pointed that experts have more total concept, conditional concept, of early components of P1 and N1 were related to choosing the spatial location of stimulus; the early effect of spatial attention began at 80 ms post-stimulus, that is, the beginning time of P1; and the C1 which was generated before P1 was not completely influenced by attention. Luo and Parasuraman [23] found that C1 could not be influenced by attention as an endogenous ERP component, and the strength of P1 maybe related to the auto processing of attention orientation caused by suddenly-appearing visual events, but the weaker activity of N1 maybe related to the dispersion of attention focus in a bigger prompt area. Hillyard and Anllo-Vento [24] found the N2 mainly reflected the mental processes of identifying target stimulus, and the N2 amplitude increased with attention area becoming bigger.

According to the previous research findings, the study ERP results indicated that the centralizing degree of attention focusing on target location of elite athletes were higher than that of general ones when they perceived the location of an offensive athlete. The elite athletes could distribute the limited attention resources to both-sides athletes rapidly and point to related action cues quickly; however, there was no difference between elite athletes and general-level athletes in the mental operation resources occupied. Moreover, the accuracy rate results indicated that the quantity and usefulness of searching and perceiving cues of elite athletes were all superior to general ones. Naturally, the mental operation resources occupied of elite athletes was more than that of general ones.

4.3 Mechanisms of judgment predominance of intuitive tactical decision-making

According to previous research [25], during the process of judging the tactical intention of offensive athletes, the latency of P3 evoked at cerebral cortex mainly reflects the time required to evaluate and classify the stimuli; the amplitude of P3 reflects the updating degree of token in working memory. The ERPs results of this study indicated that the total time (from stimulus appearance to judgment finish) had no difference; the difference only existed in updating degree of tokens in working memory. Due to the higher centralizing level of its attention which focused on the offensive athletes, high-level athletes searched for more useful action clues when they perceived offensive athletes. Moreover, the experimental task cannot separately record RTs in different stages of cognitive processing. Combining with the above-mentioned speculated time which cost in perceiving offensive athletes, thus, the real time to judge the tactical intention of elite athletes may be less than for general ones.

Normally, athletes utilize sport knowledge stored in their minds to make decisions in matches every time. The storage forms or presentation patterns of knowledge in minds are called the mental token of knowledge. The view of symbol-oriented sport cognitive psychologists is that knowledge includes declarative knowledge and procedural knowledge [26]. Then, what are differences between mental token of two kinds of knowledge of different-level fencing athletes?

In the field of visual spatial selective attention, the automatic processing and controlled processing respectively correspond to the exogenous selective attention and endogenous selective attention. Exogenous cues appear suddenly (peripheral location), and their appearance grabs the attention automatically and rapidly to detect the signal location, which belongs to the down-up processing of attention [20]. When fencing athletes carry on the tactical decision-making, according to what experimental task is required, they must perceive and distinguish the attack movement type of offensive side in the match pictures firstly, and then predict their own action effectively to deal with attack movement as a defensive player. Therefore, it is a main down-up process of exogenous selective attention when fencing athletes identify and judge the offensive players.

The early-choice theory of attention believes that spatial attention plays a role in the early stages of perception coding; attention to the location of objects is a precondition to distinguish the objects’ characteristics [21]. An ERP study conducted by Anllo-Vento and Hillyard [22] showed that the amplitude growth
movement concept and more diverse and complex goal concept and action concept than novices [27]. Cheng [18] also found that excellent badminton players have obvious predominance of declarative knowledge. The above findings show that in sports situation, experts appear to have predominance of number and level in concepts of mental token of sport knowledge when comparing with novices.

In the experimental task of this study, the tactical intentions of offensive athletes determined by fencing athletes were driven by the preset mental goal (judging the offensive athlete). Therefore, they mainly carried on mental token by declarative knowledge, such as the action schema, imagery, mental model and so on. The greater the abundance of athletes’ sports knowledge and experience, the more abundant and accurate are the action schema, imagery or mental model stored in their long-term memory system. So, the quantity, level and quality of action schema and action imagery of level-1 athletes are inferior to those of elite athletes because their years of training were not longer, although they stored a certain degree of action schema and action imagery in long-term memory storage system. Driven by the preset mental goal (judging the offensive athlete), the level-1 athletes could “call” a relatively small number of declarative knowledge tokens. Therefore, the number of new knowledge tokens formed by old knowledge tokens and the opponents’ skills information and the degree of knowledge token updating of elite athletes, were all significantly more than those of level-1 athletes. Thus, the nerve activity level of P3 was higher when elite athletes determined their tactical intention. In this line, the speculation that P3 amplitude maybe reflects the quantity and levels of declarative knowledge should be true.

The reasons for P3 peak amplitude of level-2 athletes being higher than that of level-1 athletes were mainly concerned with the task difficulty. The effort expended by level-2 athletes was greater than that by level-1 athletes because the experimental task was more difficult for level-2 athletes, so the updating number of declarative knowledge tokens of tactics intention in working memory and the mental operation resources occupied and mental energy of level-2 athletes were more than that of level-1 athletes.

The ERP results also indicated that the updated number of knowledge tokens in male athletes’ working memory was significantly greater than that of female athletes. As we all know, there are significant differences in athletic ability and sports performance between female and male athletes for each sports item. According to this study’s results, despite inherent body shape and body function, the reasons causing above differences should include the cognitive processing abilities in sports situations.

4.4 Mechanisms of anticipation predominance of intuitive tactical decision-making

It can be seen from the accuracy rate results that non-level athletes guess randomly to judge tactical intention rather than anticipate purposefully. As the years of training of non-level fencing athletes were only 2-3 years, and they were short of adequate knowledge of specialty sports and competitions experience, they reduced the cost of accuracy rate in exchange for the speed (the fastest RT) when making decisions. So, with a lack of sufficient knowledge of specialty sports and competition experience, it is impossible to have real intuitive thinking in decision-making.

Subjected to the rules of fencing competition “right of priority judgment”, fencing athletes were too likely to adopt defense tactics in actual games to usually choose defense tactics in experimental task regardless their grade of athletic skill. In addition, the possible results of tactical decision-making task in this experiment just were defense and counterattack, and the total number of 2/3 was decision-making tasks with defense tactics choice. As a result, accuracy rate of decision-making of different group athletes showed no significant difference.

Previous ERP studies show that PSW is a positive slow wave after P3. Wei et al. [28] adopted the association model of the cue word, the target word, studied the ERP characteristics of meaning association of Chinese characters in the entire field of vision. The results showed that in the cognitive process of Chinese characters, PSW and P3 represent the different cognitive stages. PSW was mainly related to the association processing stage after the meaning processing stage of Chinese characters. When PSW appeared, it implied that the cognitive processing stage of P3 represented had been completed and began to enter the next processing stage-association stage. Therefore, PSW not only reflects the completion of information processing, but also relates to cognitive multiplexing, such as association and guessing of the shape and sound of characters and words.

ERP results in this study indicated that the intuitive anticipation speed of elite athletes was faster than that of general ones, but the mental operational resources occupied were much large than the level-1 ones. The above findings by McPherson and Cheng were that expert athletes had obvious predominance of conceptual declarative knowledge. However, the important characteristics of intuitive decision-making in sports situations are the large extensity, great time pressure and uncertain outcome of problems. If athletes only use concepts to token the internal and external information, it could not meet the needs of complex, changing, fast and uncertain competition situation. So, athletes token sports knowledge and experience to more schemas, imagery, a mental model and rules and so on, in order to make effective decisions quickly. Therefore, the quantity and level of token forms of procedural knowledge also is an important factor in interpreting difference of intuitive decision-making between expert and novice fencing athletes.

Due to much more years of training, the procedural degree and automation degree of high level athletes are obviously higher than that of general ones, the number of production rules and level of internal composition of production rules are also obviously more than those of general ones; the high-level athletes tend to activate top-down production system in the stage of intuition anticipation, carry out tactical intuitive decision-making according to a larger number of production rules, and occupy more mental operational resources to make correct decisions. However, general ones mainly use...
declarative knowledge tokens in the stage of intuitive anticipation; the decision-making speed is relatively slow. Even if general athletes carry out mental tokens with procedural knowledge, influencing by the small number and poor level of production rules, their accuracy rate of decision-making was lower. Therefore, it can be speculated that the PSW amplitude maybe reflect the quantity and level of production rules of procedural knowledge tokens.

As for the reason of PSW peak amplitude of level-2 athletes being higher than that of level-1 athletes, it was similar to the reasons of higher P3 peak amplitude of level-2 athletes than that of level-1 athletes, in other words, it mainly concerned the task difficulty.

5. Conclusion

Tactical decision-making of elite, level-1 and level-2 fencing athletes belong to intuitive decision-making, while that of non-level fencing athletes was mainly random guessing. Elite fencing athletes focus on veracity and general-level fencing athletes focus on speed when they making tactics decisions.

During the process of intuitive tactical decision-making, the pointing degree of exogenous attention and the updating degree of mental token in working memory of elite fencing athletes were higher than those of general-level fencing athletes. The speed of intuitive anticipating of elite fencing athletes was faster than that of general level fencing athletes and the mental operation resources occupied by elite fencing athletes were more than those of general-level fencing athletes. The possible neural mechanism of decision-making predominance of high level fencing athletes was that the nerve activity levels of P1, P3, PSW evoked at the special regions of cerebral cortex were higher, and the time of PSW evoked within the special regions of cerebral cortex was earlier. These results suggest that the ERP index of latency and amplitude of P3 and PSW could be the object indexes which evaluating the number and level of mental token of athletic knowledge and experience. In a word, the modern sports fencing game is not just a contest of physical strength, but also a bout of knowledge.

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References