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Hand-related action words impair action anticipation in expert table tennis players: behavioral and neural evidence

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Keywords:	hand-related action words, action anticipation, table tennis, P3, N2

Abstract:	Athletes extract kinematic information to anticipate action outcomes. Here, we examined the influence of linguistic information and its underlying neural correlates on anticipatory judgment. Table tennis experts and novices remembered a hand- or leg-related verb or a spatial location while predicting the trajectory of a ball in a video occluded at the moment of the serve. Predictions by experts were more accurate than novices, but experts' accuracy significantly decreased when hand-related words vs. spatial locations were memorized. For nonoccluded videos with ball trajectories congruent or incongruent with server actions, remembering hand-related verbs shared cognitive resources with action anticipation only in experts, with heightened processing load (increased P3 amplitude) and more efficient conflict monitoring (decreased N2 amplitude) vs. leg-related verbs. Thus, action anticipation required updating of motor representations facilitated by motor expertise but was also affected by effector-specific semantic representations of actions, suggesting a link from language to motor systems.

Expert table tennis players extract kinematic information around hand to anticipate action outcomes. Our findings add a new perspective that action anticipation also requires effector-specific semantic representations, because hand-related action words have negative influence on anticipatory judgment. It provides support for a link from language system to motor system.

Hand-related action words impair action anticipation in expert table tennis players: behavioral and neural evidence

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Short title: Action words impair action anticipation

ABSTRACT

Athletes extract kinematic information to anticipate action outcomes. Here, we examined the influence of linguistic information and its underlying neural correlates on anticipatory judgment. Table tennis experts and novices remembered a hand- or leg-related verb or a spatial location while predicting the trajectory of a ball in a video occluded at the moment of the serve. Predictions by experts were more accurate than novices, but experts' accuracy significantly decreased when hand-related words vs. spatial locations were memorized. For nonoccluded videos with ball trajectories congruent or incongruent with server actions, remembering hand-related verbs shared cognitive resources with action anticipation only in experts, with heightened processing load (increased P3 amplitude) and more efficient conflict monitoring (decreased N2 amplitude) vs. leg-related verbs. Thus, action anticipation required updating of motor representations facilitated by motor expertise but was also affected by effector-specific semantic representations of actions, suggesting a link from language to motor systems.

KEYWORDS: hand-related action words; action anticipation; table tennis; P3; N2

1. INTRODUCTION

Action anticipation involves observing and predicting the behavior of other individuals (Reilly, Williams, Nevill, & Franks, 2000). It is a core skill that enables athletes to save time for subsequent execution of, for example, an effective ball interception in racquet sports. Our recent studies have shown that elite athletes present an ability superior to novices in anticipating the outcomes of the movements of opponents (Wang, Ji, & Zhou, 2019; Zhao, Lu, Jaquess, & Zhou, 2018). Neuroimaging evidence has long claimed that action processing depends on a network of brain areas known as the mirror neuron system (Gatti et al., 2017; Iacoboni et al., 1999; Rizzolatti & Craighero, 2004), which is thought to contribute to skilled outcome prediction (Makris & Urgesi, 2015; Smith, 2016). However, strong links exist between the motor and language systems, and the theory of the somatotopy of action words suggests that information concerning language and actions might interact in distributed neuronal assemblies (Heiser, Iacoboni, Maeda, Marcus, & Mazziotta, 2015; Pulvermüller, 2005; Pulvermüller & Fadiga, 2010; Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005). Additional studies have shown that both motor movements and memory for action-related words rely on overlapping processing resources (Shebani & Pulvermüller, 2013). From the perspective of the attentional capacity model, if two kinds of cognitive processing share resources, the conduct of one task will have likely negative consequences on another concurrent task (Hula & McNeil, 2008; Kahneman, 1973). The present study aims to explore whether semantic processing of effector-specific words interferes with domain-specific action anticipation differently in expert players than in novices.

The theory of embodied semantics proposes that the processing of linguistic stimuli that refer to motor concepts can be shaped by related aspects of the entire body and activates the sensorimotor regions that also subserve perceiving and acting (Barsalou, 1999, 2008; Willems & Casasanto, 2011). For example, the word "grasp" strongly stimulates cortical regions that are also active during finger movements (Boulenger, Hauk, & Pulvermüller, 2009; Boulenger, Shtyrov, & Pulvermüller, 2012). Furthermore, transcranial magnetic stimulation studies have found that magnetic pulses stimulating the motor system modulate the processing of action-related words (Vukovic, Feurra, Shpektor, Myachykov, & Shtyrov, 2017). This evidence for motor cortex activation in the comprehension of verbs provides partial support for a connection from the motor system to the language system. However, whether a reverse link in such a model exists, that is, from the language system to the motor system, still requires investigation. Although the results from our recent study (Wang et al., 2019) indicate the involvement of semantic areas in action anticipation, the questions about whether and how linguistic stimuli affect action processing are as yet unanswered.

The effects of linguistic stimuli on action processing appear to be specific to effector type. Mollo, Pulvermüller, and Hauk (2016) have found that congruency between the effector used for the initial movement (e.g., hand or foot) and subsequent action word (e.g., hand- or foot-related verb) influences the activation of both motor areas and semantic areas in the brain. Their finding suggests the embodiment of semantics in sensorimotor systems. Therefore, we hypothesize that in experienced racquet sports players, such as table tennis players, hand-related action words will interfere with action anticipation more than foot-related action words will because the action executed in table tennis is primarily focused on hand-related movements. Studies have confirmed that expert players use kinematic information (e.g., movements of the racquet arm) prior to ball flight to predict the action outcomes of opposing players better than novices do (Canal-Bruland, van Ginneken, van der Meer, & Williams, 2011; Fukuhara, Ida, Ogata, Ishii, & Higuchi, 2017; Zhao et al., 2018). Thus, it appears that racquet sports players pay more attention to the movements of the racquet hand and arm before contact is made with the ball (Piras, Lanzoni, Raffi, Persiani, & Squatrito, 2016). As such, the specific influence of hand-related action words on anticipatory performance can be tested in racquet sports players, and a finding of congruency for hand-related action words in these players would be strong evidence for a link between the motor cortex and language areas.

The neural correlates underlying anticipatory performance influenced by linguistic information remain unclear and should be determined to further understanding of action anticipation behavior. Because action anticipation in racquet sports has a high demand for rapidly detecting the ball direction, event-related potentials (ERPs) with high temporal resolution can be used to assess the underlying neural correlates. Examining the ERP will enable the assessment of brain dynamics during the information processing capacity of actions and words (Kok, 2001). Recently, Shangguan and Che (2018) found that compared with second-grade players, professional players showed smaller amplitudes for the N1 and N2 components of the ERP but larger amplitudes for the P2 and P3 ERP components during anticipation (Jin et al., 2011), which suggests the superior efficiency of information extraction and of cognitive resource allocation in experts. This raises the question of what underlying strategy expert players use to predict action outcomes while processing action words.

Although it has been shown that expert players predict action outcomes based on previously presented body kinematic information (Aglioti, Cesari, Romani, & Urgesi, 2008; Causer, Smeeton, & Williams, 2017; Tomeo, Cesari, Aglioti, & Urgesi, 2012), little is known about their ability to anticipate fooling (or incongruent) behaviors. In any competitive setting, players aim to fool others. They attempt to provide misleading kinematic information, that is, kinematic clues that are incongruent with the visually presented consequences of actions. Semantic knowledge is typically involved in processing expectancy violations (Kutas & Hillyard, 1984; Parmentier, Pacheco-Unguetti, & Valero, 2018) not only for verbal stimuli but also for actions (Balconi & Caldiroli, 2011; Lee, Huang, Federmeier, & Buxbaum, 2018). This raises another question, that of the strategy underlying the processing of unexpected outcomes and action words.

The present study combines the use of a dual-task paradigm with ERP methodology to address these questions. The study is presented herein as two experiments that explore both the behavioral and neural aspects. Experimental trials were initiated as expert table tennis players and novices engaged in a working memory task (Baddeley & Hitch, 1974) in which they memorized hand- or leg-related action words and memorized the spatial location of three black squares in an otherwise blank matrix of 16 squares (as a control condition) presented on a computer screen. While the participants held the words and spatial locations in working memory, a video of a table tennis serve was presented on the computer screen. The participants were asked to anticipate (predict) where the ball would land on each serve. We hypothesize that if the memorized action-related word and action processing share limited resources, as is suggested in the theory of somatotopy of action words and in the attentional capacity model, then expert players will show worse anticipatory performance than novices. In addition, expert players will show distinct brain activity for congruent vs. incongruent conditions, specifically, (1) for a hand-related word vs. either a leg-related word or a spatial location and (2) for the trajectory and landing of a ball after a table tennis serve that appears congruent vs. incongruent with the actions of a server.

2. EXPERIMENT 1

2.1 Methods

2.1.1 Participants. In total, 33 expert table tennis players and 35 college students from the same college who had no professional training in table tennis (novices) were recruited for the study (Table 1). The experts had more than 7 years of table tennis training. Experts and novices did not significantly differ in age ($t_{(66)} = 1.80$, $p = 0.076$, 95% confidence interval [-0.075, 1.448]) or in gender ratio ($\chi^2 = 0.07$, $p = 0.797$). All participants had normal or corrected-to-normal vision and had no history of psychiatric, medical, or neurological illness. All participants provided written informed consent prior to the study. The experimental protocol was approved by the ethics committee of Shanghai University of Sport.

Table 1. Experiment 1 Participant Demographic and Training Characteristics

Characteristic	Experts	Novices
Number	33	35
Sex, (No. males/females)	15/18	17/18
Age, mean ± SD, y	19.57 ± 1.51	20.35 ± 1.62
Years of training, mean ± SD	12.06 ± 2.07	none
Training frequency (No. of sessions/week)	12	none
Training time (h/session)	2	none

2.1.2 Stimuli. Twenty videos depicting a female table tennis player serving, with an equal probability of serving to the left and right, were recorded from the perspective of her opponent (Canon 5D Mark III; resolution, 1280 × 720 pixels). The captured videos were processed using Adobe Premiere software (Adobe Systems Incorporated; San Jose, CA, USA). Because of the expert players' superior ability to extract kinematic information, each video was temporally occluded at the point of the racket-ball contact. The server's face in each video was blurred to eliminate the influence of facial features and head motion, but the server's kinematic information was retained.

The lexical stimuli used in the experiment consisted of 30 hand-related action words and 30 leg-related action words in Chinese. They were matched for valence, arousal, imageability, and word frequency (Table 2). The matching was determined by our pilot testing of an independent sample of 10 native-Chinese speakers who used a semantic rating procedure with a five-point scale. The spatial stimuli comprised 20 two-dimensional matrices, each consisting of 4 × 4 squares, with each matrix containing 3 black squares and 13 white squares (Figure 1). The positions of the three black squares within the matrix were altered to provide a unique spatial stimulus for each trial.

Table 2. Psycholinguistic properties of the hand- and leg-related words (mean ± standard deviation)

Psycholinguistic feature	Hand-related words	Leg-related words	*z score*	*p value*
Valence	3.02 ± 0.59	2.99 ± 0.75	−0.022	0.983
Arousal	3.11 ± 0.41	3.18 ± 0.40	−0.712	0.476
Imageability	4.40 ± 0.89	4.40 ± 1.25	−0.127	0.899
Word frequency	3.30 ± 1.39	3.07 ± 1.23	−0.769	0.442
Hand relatedness	4.60 ± 0.72	2.50 ± 1.36	-4.234^{**}	< 0.001
Leg relatedness	1.93 ± 1.11	4.83 ± 0.59	-4.769^{**}	< 0.001

Note: The differences in valence, arousal, imageability, word frequency, hand relatedness, and leg relatedness between hand-related words and leg-related words were assessed using the Wilcoxon signed rank test. $^{**}p < 0.01$.

2.1.3 Task and procedure. There were four conditions in the action anticipation task (Figure 1). A control condition during which no stimulus was memorized to provide a baseline to compare pure anticipatory performance between experts and novices. The other three conditions were the interference trials, requiring the memorization of hand-related words, leg-related words, or spatial locations. Participants were instructed to read and encode (memorize) three action-related words presented serially on a computer screen or 3 black squares presented at the same time in a matrix with 13 blank squares (16 squares in total). A video of a woman performing a table tennis serve was presented next, and participants were required to predict the ball trajectory and landing (while retaining the words or locations of the squares presented in that trial in working memory). Finally, recognition memory performance for the action-related words or for the spatial locations was tested using a forced selection task to ensure that the working memory task was being performed so that interference in the action anticipation task could be assessed.

Participants received different instructions for the four conditions. In the control condition, participants were required only to anticipate as quickly and as accurately as possible the fate of each served ball by pressing the "F" key on a keyboard for predicting that the ball would land to the left, or "J" for predicting the ball would land to the right.

In the hand- and leg-related word interference conditions, participants were asked to memorize three verbs in each trial and to remember them while completing the action anticipation task as described for the control condition. They were then tested to determine whether they recognized the words that had appeared during encoding. Responses were given by pressing the "F" or "J" key on the keyboard for the correct word appearing on the left side of the computer screen or on the right, respectively. In the spatial interference condition, participants were instructed to memorize the locations of three black squares in the matrix and to remember them while completing the action anticipation task as described for the control condition. For spatial recognition testing, the participants responded by pressing the space bar on the keyboard when the matrix matched the one that had been shown at the start of that trial or to withhold responding when the matrix differed.

The four conditions were run as separate blocks, with 20 trials in each block. The order of the four blocks was counterbalanced across participants using a Latin-square design. The 20 videos in each block were presented randomly. Interference items to be memorized in each trial were selected and presented randomly from sets of 30 hand-related verbs, 30 leg-related verbs, and 20 matrices for the three interference conditions. Clearly written instructions were given to all participants prior to each block. Participants practiced before each formal test to familiarize themselves with the task. A short break was provided between each block.

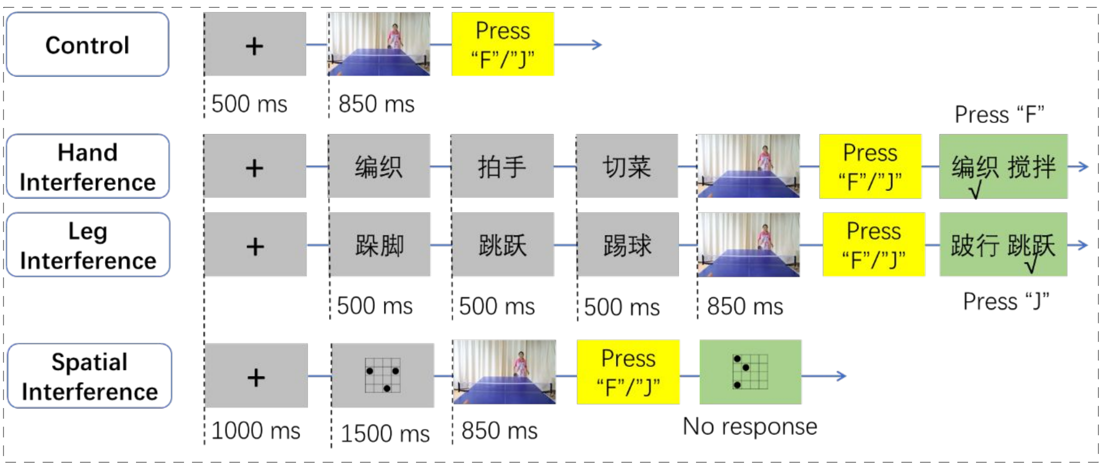

Figure 1. The procedure showing example trials for the four conditions: control, hand interference, leg interference, and spatial interference. Participants were required to respond twice in the three interference conditions: once for action anticipation (yellow squares) and once for word or spatial recognition (green squares). The plus symbol indicates the start of each trial. Chinese symbols shown are for knit (编织), clap (拍手), chop (切菜), stir (搅拌), stamp (跺脚), skip (跳跃), kick (踢球), and limp (跛行).

During the experiment, participants sat in a quiet room approximately 60 cm from a 19-inch Lenovo computer monitor on which stimuli were presented on a gray background. The experimental task was designed and run using E-Prime software (version 2.0, PST, Inc.; Pittsburgh, PA, USA).

2.1.4 Data and statistical analyses. We calculated the percentage of correct responses (accuracy) and response time (RT) for each experimental condition. We then conducted an arcsine transformation of the accuracy (Hogg & Craig, 1995). Trials in which participants responded incorrectly for recognition memory were discarded from the analysis (hand-interference condition: 0.56 ± 1.09 of the 20 trials; leg-interference condition: 0.44 ± 0.80 of the 20 trials; spatial-interference condition: 0.52 ± 0.91 of the 20 trials). There is no correlation between group factor and condition factor on the number of error trials ($\chi^2 = 0.99$, $p = 0.609$). Both arcsine-transformed accuracy and RT were assessed using a two-way mixed-model analysis of variance (ANOVA), with group (expert vs. novice) as the between-subject factor and condition (control, hand-, leg-, and spatial-interference) as the within-subject factor.

Statistical analysis was performed using SPSS, version 20.0 (IBM SPSS, Inc.; Chicago, IL, USA). The post hoc tests of significant main effects were corrected using Bonferroni corrections. A simple effects test, which also used Bonferroni corrections, was conducted when the interaction was significant. All tests were two-sided, and $p < 0.05$ was considered statistically significant. Partial eta-squared (η_p^2) values are reported to demonstrate the effect size in the ANOVA.

2.2 Results. For the arcsine-transformed accuracy, the ANOVA analysis showed significant main effects of both group ($F_{(1,66)} = 89.26$, $p < 0.001$, $\eta_p^2 = 0.575$) and condition ($F_{(3,198)} = 30.98$, $p < 0.001$, $\eta_p^2 = 0.319$), with the two-way interaction of group × condition also significant ($F_{(3,198)} = 2.94$, $p = 0.034$, $\eta_p^2 = 0.043$). The simple effects analysis of the interaction showed that both experts and novices exhibited higher arcsine-transformed accuracy in the control condition than in the three interference conditions (all $p \leq 0.001$). However, arcsine-transformed accuracy was lower in the hand-interference condition than in the spatial-interference condition among experts ($p = 0.018$) but not novices (Figure 2).

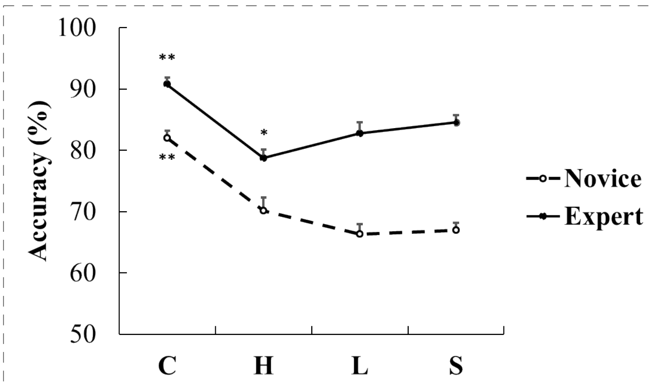

Figure 2. Mean accuracy (in percent) in the control (C), hand-related (H), leg-related (L), and spatial-related (S) interference conditions for expert and novice groups. Bars represent standard error of the mean. $^{*}p < 0.05$ vs. S; $^{**}p < 0.01$ vs. H, L, or S.

For RT, the ANOVA analysis showed significant main effect of condition ($F_{(3,198)}$ = 10.12, p < 0.001, η_p^2 = 0.133). Further analysis indicated that RT in the control condition was higher than that in the hand-interference condition (p = 0.001) and leg-interference condition (p < 0.001). The main effect of group ($F_{(1,66)}$ = 2.36, p = 0.129, η_p^2 = 0.035) and the group × condition interaction ($F_{(3,198)}$ = 1.21, p = 0.308, η_p^2 = 0.018) were not significant.

2.3 Discussion of Experiment 1. The lower accuracy in the hand-interference condition vs. no interference for the expert group suggested that the memory of hand-related action words significantly influenced the anticipatory judgment of the outcome of a serve in table tennis, consistent with our hypothesis. This finding has several implications. First, although there is strong evidence that picking up visual kinematic information is crucial to anticipatory judgment in racquet sports such as table tennis (e.g., Zhao et al. (2018)), the present study provided evidence to suggest that linguistic stimuli were also taken into account by table tennis players in action anticipation. According to the somatotopy of action words theory, both action anticipation and semantic memory for action-related words would rely on overlapping and interfering processing resources. Second, the significant influence of hand-related action words on action anticipation found in Experiment 1 is consistent with our hypothesis and supports the congruency effect of the effector type. Thus, from a practical viewpoint, players and coaches may wish to avoid the use of hand-related action words that are unrelated to table tennis actions during competitions because the athletes' processing of the congruent words may impair their action anticipation.

3 Experiment 2

3.1 Methods

3.1.1 Participants. The participants in Experiment 2 comprised 26 expert table tennis players and 29 college students with no table tennis training who were also recruited from the same college. None of these participants took part in Experiment 1. The demographic and training characteristics of participants in Experiment 2 are given in Table 2. Experts and novices in Experiment 2 also did not significantly differ in age ($t_{(53)}$ = 1.55, p = 0.128, 95% confidence interval [-0.199, 1.545]) or in gender ratio (χ^2 = 0.03, p = 0.875).

Table 2. Experiment 2 Participant Demographic and Training Characteristics

Characteristic	Experts	Novices
Number	26	29
Sex, (No. males/females)	12/14	14/15
Age, mean ± SD, y	19.52 ± 1.60	20.19 ± 1.62
Years of training, mean ± SD	11.92 ± 2.04	none
Training frequency (No. of sessions/week)	12	none
Training time (h/session)	4	none

3.1.2 Stimuli, task, and procedure. The same 20 videos processed by Adobe Premiere software used in Experiment 1 were presented in Experiment 2 but without the occlusion. However, each video was interrupted and exported into a file containing 30 continuous frames of images (resolution, 640 × 360 pixels) around the racket contact with the ball (the 17th frame). Thus, each file included the server's initial swing (body kinematics video clip; 16 frames) and the visible ball trajectory until the ball touched the table (ball trajectory video clip; 13 frames). We manipulated the videos to produce two types. Each body kinematics video clip was combined with either its own ball trajectory video clip (congruent video clip) or with the ball trajectory video clip of a serve in the opposite direction (incongruent video clip) (Wang et al., 2019). This resulted in 40 modified videos that included 20 congruent action videos and 20 incongruent action videos (Figure 3). In the action anticipation task, after the entire video was presented, the participants were required to report the correct direction (left or right) where the ball would travel given the preceding body kinematics, as accurately as possible and regardless of the subsequent ball trajectory.

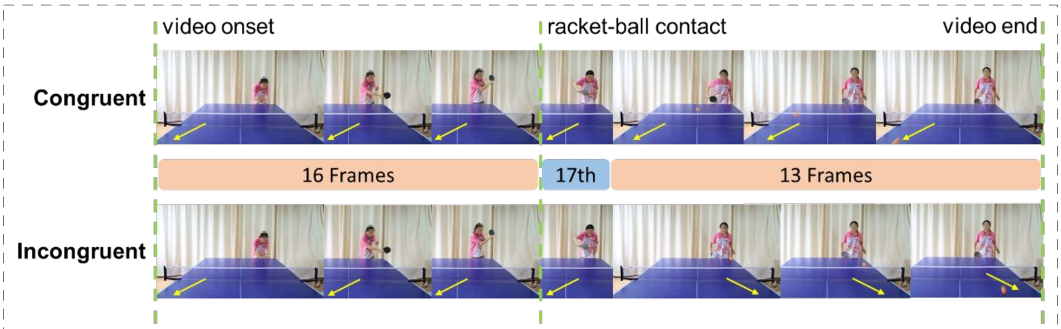

Figure 3. Exemplar frames of videos with congruent action and with incongruent action. A single table tennis player qualified as a National Player of the First Grade served the ball in each video. The difference between the congruent and incongruent videos occurred immediately after the racket contacted the ball (17th frame), with the direction of the body kinematics and ball trajectory being either matched (congruent) or mismatched (incongruent).

The same three experimental conditions (hand-, leg- and spatial-interference) from Experiment 1 were used in Experiment 2. In addition, the distractors used for the three conditions as well as the experimental procedures were identical to those used in Experiment 1. Participants were also required to simultaneously complete both the action anticipation task and the working memory task, as before. The three conditions were presented as separate blocks, with 120 trials in each block. The 40 videos were presented three times in each block.

3.1.3 ERP data recording. Brain electrical activity was recorded from 64 Ag/AgCl electrodes arranged according to the International 10-20 System, with a sampling rate of 1000 Hz (Brain Products GmbH; Munich, Germany). The vertical electrooculogram (VEOG) was placed below the left eye and horizontal electrooculogram (HEOG) was placed at the lateral-orbitally of the right eye. Electroencephalography (EEG) activity was online referenced to the FCz site; the AFz site served as the ground electrode. All electrode impedances were maintained below 10 kΩ.

3.1.4 Data and statistical analyses

3.1.4.1 Behavioral analysis. In order to confirm the results of Experiment 1, the arcsine-transformed accuracy and RT of the participants were analyzed and the results assessed as above using a two-way mixed-model ANOVA, with group (expert vs. novice) as the between-subject factor, and condition (hand-, leg-, and spatial-interference) as the within-subject factor. Trials in which participants responded incorrectly for recognition memory were also discarded from the analysis (hand-interference condition: 4.05 ± 2.89 of the 120 trials; leg-interference condition: 3.77 ± 3.26 of the 120 trials; spatial-interference condition: 4.41 ± 4.60 of the 120 trials). There is no correlation between group factor and condition factor on the number of error trials ($\chi^2 = 2.35$, $p = 0.309$).

3.1.4.2 ERP analysis. The EEG activity was preprocessed in MATLAB (R2012b, The MathWorks, Inc.; Natick, MA) (Zhang, Ristaniemi, & Cong, 2020). The raw EEG data were checked by visual inspection to remove nonstationary artifacts. Then, the signals were re-referenced to the mean of the left and right mastoid signals, and the online reference was recovered to FCz. A 50-Hz notch filter and a band-pass filter (low cutoff, 0.1 Hz; high cutoff, 30 Hz; slope, 24 dB/octave) were applied to the re-referenced EEG signals. The ocular artifacts were removed from the filtered EEG data using independent component analysis (Mennes, Wouters, Vanrumste, Lagae, & Stiers, 2010). The ocular artifact–corrected EEG data were then segmented, starting 500 ms prior to the frame of racket-ball contact onset to 1000 ms after the onset for each experimental condition. The baseline was corrected using the −500 ms to 0 ms pre-contact period (Lu, Yang, Hatfield, Cong, & Zhou, 2020). Epochs with signals that exceeded ±100 μV were rejected. Then, the epochs for each condition were averaged, and the ERP difference wave was obtained by subtracting the congruent condition from the incongruent condition. Because of the complexity of video stimulation, a fast Fourier transform algorithm was applied to further filter the difference signals to reduce the impact of both low and high frequency artifacts (0.5-30 Hz). Finally, we analyzed the averaged amplitudes of the N2 component and of the P3 component across different sets of electrodes in accordance with grand-averaged waveforms and the topographical distribution of the grand-averaged ERP activity (for N2: Fz and FCz; for P3: FCz and Cz) (Liu et al., 2017; Shangguan & Che, 2018). The time windows were 250–300 ms for N2 and 320–380 ms for P3. The mean amplitude for each component in the selected electrode sites was assessed using a 2 (group: expert and novice) × 3 (condition: hand-, leg-, and spatial-interference) ANOVA. Statistical analyses were conducted as described above for Experiment 1.

3.2 Results

3.2.1 Behavioral results. For the arcsine-transformed accuracy, the 2 × 3 ANOVA results showed a significant main effect of group ($F_{(1,53)} = 14.18$, $p < 0.001$, $\eta_p^2 = 0.211$). Further analysis indicated that anticipatory accuracy was higher in experts than in novices. The two-way interaction of group × condition was also significant ($F_{(2,106)}$ = 5.04, p = 0.008, η_p^2 = 0.087). The simple effects analysis revealed that a signiciant difference was found only in the experts, such that arcsine-transformed accuracy in the hand-interference condition was significantly lower than that in the leg-interference condition (p = 0.015) and in the spatial-interference condition (p = 0.009) (Figure 4). For RT, the results showed no significant effect of any factors ($F \leq 3.42$, $p \geq 0.070$).

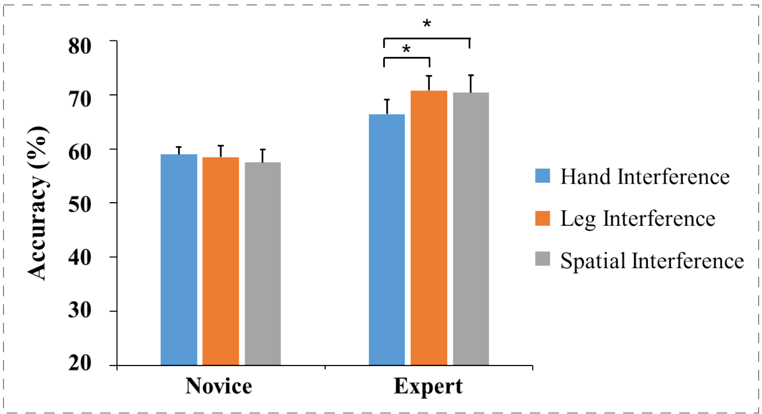

Figure 4. Mean accuracy of the hand-, leg- and spatial-interference conditions in the expert and novice groups. Error bars represent standard error of the mean.$^{*}p < 0.05$ between the conditions indicated.

3.2.2 ERP results

3.2.2.1 N2 component. The results of a 2 × 3 ANOVA revealed that although the main effects of group and of condition were not significantly different, the interaction between group and condition was significant ($F_{(2,106)}$ = 9.231, $p < 0.001$, η_p^2 = 0.148). The simple effects analysis revealed a higher N2 amplitude in the hand-interference condition than in the leg-interference condition for novices (p = 0.002). By contrast, the N2 amplitude in the hand-interference was lower than that in the leg-interference condition for experts (p = 0.029) (Figure 5 and Figure 6).

3.2.2.2 P3 component. The results of a 2 × 3 ANOVA indicated that the main effect of group was significant ($F_{(1,53)}$ = 12.742, p = 0.001, η_p^2 = 0.194) and that the group × condition interaction was also significant ($F_{(2,106)}$ = 4.871, p = 0.009, η_p^2 = 0.084). Simple effects analyses showed that the P3 amplitude was larger for the hand-interference condition than for the leg-interference condition in experts (p = 0.003), whereas no significant difference was found among the three conditions in novices (Figure 5 and Figure 6).

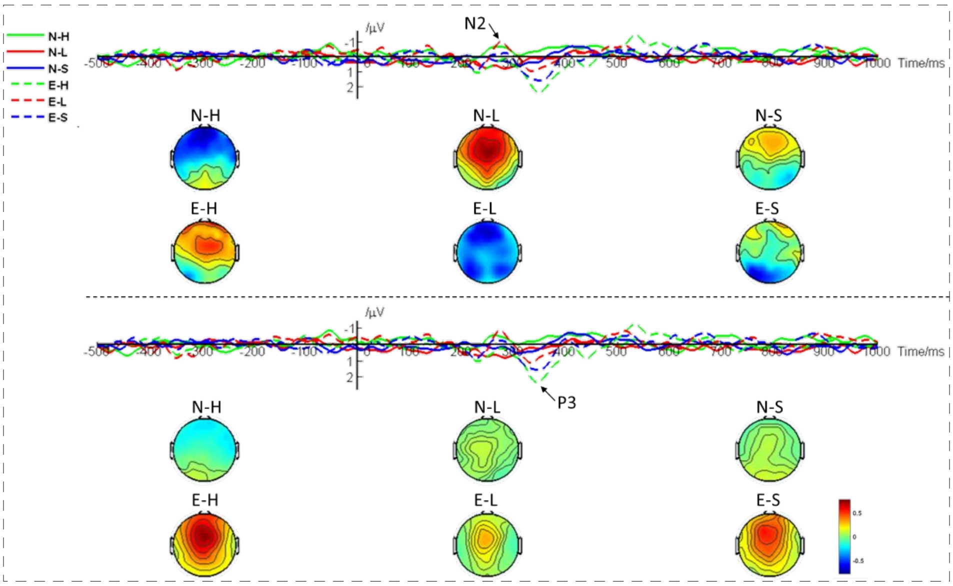

Figure 5. The grand-averaged event-related potentials elicited by the frame of racket-ball contact in the videos at the FCz and the scalp topography reflect the distribution of the N2 component (upper panel) and P3 component (lower panel). N-H represents novice hand-interference condition; N-L, novice leg-interference condition; N-S, novice spatial-interference condition; E-H, expert hand-interference condition; E-L, expert leg-interference condition; E-S, expert spatial-interference condition.

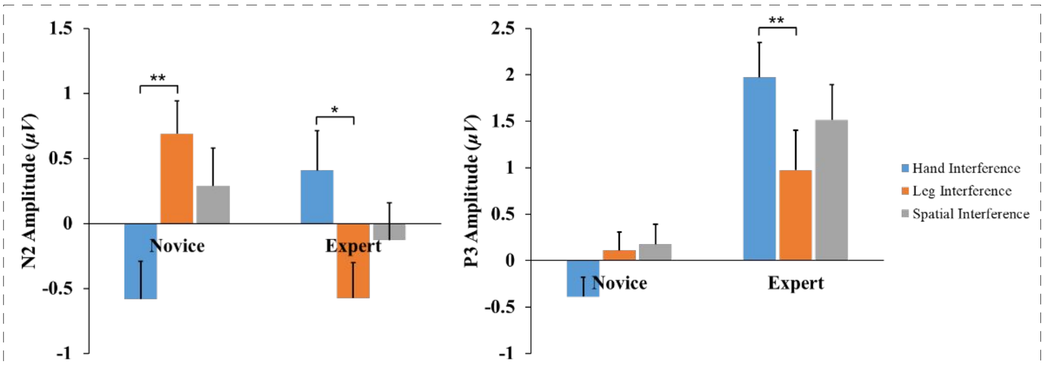

Figure 6. The N2 and P3 amplitudes in response to the three experimental conditions (hand interference, leg interference and spatial interference) in both groups (novice and expert). $^{*}p < 0.05$ and $^{**}p < 0.01$ between the conditions indicated.

3.3 Discussion Experiment 2. The behavioral results of Experiment 2 confirmed those of Experiment 1 and additionally indicated that the congruency effect between action-related words and serving actions occurred when experts processed expected or unexpected outcomes in complete (not occluded) serving action videos. The ERP results showed that hand-related action words differentially affected dynamic neural responses (N2, P3) to action processing in expert table tennis players compared with novices.

4 GENERAL DISCUSSION

To explore the relationship between motor and language systems, we investigated whether action words elicited cognitive and neuronal processing in action anticipation that was comparable between expert table tennis players and novices. Consistent with our hypothesis, memory of hand-related action words impaired anticipation of both temporally occluded actions and of fooling (incongruent) actions only for expert table tennis players. On the neuronal level, hand-related action words influenced the amplitudes of the N2 and P3 ERP components in experts during action anticipation in a different manner from how they influenced novices. For experts, the N2 amplitude was less pronounced in hand-interference conditions compared with leg-interference conditions, whereas the P3 amplitude was more pronounced in the hand-interference than leg-interference conditions. These results suggest that the processing of congruent words and actions share limited-capacity, parallel processing resources, providing supporting evidence for both the somatotopy of action words model and the attentional capacity model.

In Experiment 1 of the present study, which explored a temporally occluded paradigm, the anticipatory performance in all three interference conditions was lower than that in the control condition for both experts and novices. However, interference of the anticipatory task was greater in experts when they were required to simultaneously remember hand-related action words compared with remembering spatial locations. By contrast, there was no apparent modulation of the three types of interference in novices. In studies using a traditional dual-task paradigm, decreased performance of the main task is classically interpreted in terms of shared cognitive resources with the secondary task (Hiraga, Garry, Carson, & Summers, 2009). The greater deterioration of action anticipation suggests that processing table tennis actions for expert players involves semantic representations, which would also be used in retention of action-related words. Moreover, this interference between action anticipation and the action-related word was specific to the congruency between the effector type and the action word. Specifically, only hand-related action words, not foot-related words, decreased the athletic expertise–related prediction of expert table tennis players. These results are consistent with the somatotopy of action words model, which suggests that language and action with the same effector type may interact in overlapping neuronal assemblies.

The results of Experiment 2 suggested that similar action-related word interference occurred when experts distinguished an unexpected action sequence, indicating the validity of action-related word interactions found in the context of interactive sports. This interference also aligns with results from neuromagnetic studies that have extended the classic N400 effect to the perceived “mismatch” between predicted and observed actions (Amoruso et al., 2014; Lee, Huang, Federmeier, & Buxbaum, 2018; Reid & Striano, 2008). The N400 effect is a neural measure of semantic processing that is detected following the onset of incongruent verbal stimuli (Kutas & Federmeier, 2011). Unexpected action outcomes may especially induce enhanced semantic processing (Amoruso et al., 2014; Maffongelli et al., 2015). Therefore, it is not surprising that retaining the memory of hand-related verbs, which definitely involves semantic processing, impaired the ability of expert players with a lot of motor experience to detect whether a table tennis player was performing a congruent or an incongruent action sequence.

In assessing the readiness of players to respond to varying outcomes, it is important to examine their neural activity following the presentation of body kinematics and while they retained words or spatial locations in their memory. Based on the attentional capacity model, the present study focused on the N2 and P3 ERP components because they reflect conflict resolution and cognitive resource allocation, respectively (Kałamała, Szewczyk, Senderecka, & Wodniecka, 2018; Polich, 1996). The novices exhibited an increased N2 amplitude in the hand-interference condition compared with that in the leg-interference condition. By contrast, the N2 amplitude in experts showed the opposite response and also showed a larger P3 amplitude in the hand-interference condition than in the leg-interference condition. The distinct differences in the N2 and P3 amplitudes in the two interference conditions between experts and novices suggest that the processing of unexpected vs. expected outcomes stems from different mechanisms.

Table tennis experts generate hand-related representations from years of specific professional training that helps them to respond to common hand-related action events in sports even for fates of balls incongruent with the actions of the server (Alexander & Brown, 2011). When hand-related action words were required to be processed in parallel with action anticipation in the present study, experts, with a repertoire of representations greater than that of novices, could easily retrieve cognitive resources to accomplish both action anticipation and word memorization. Taking the higher response accuracy of experts than novices into account, the increased P3 amplitude in the hand-interference condition indicates that hand-related representations may underpin superior action anticipation. Moreover, the P3 amplitude results may be due to the relatively higher processing load required to inhibit a response to the fooling (incongruent) ball trajectory or to the use of the initial body movements to predict the action outcomes in the incongruent condition (Malcolm, Foxe, Butler, & De Sanctis, 2015).

Cognitive resources in experts are used to make adjustments in control to dynamically adapt to expectancy conflict in incongruent conditions (Lo & Sharon, 2018). The changes in the N2 amplitudes in the hand-interference and leg-interference conditions in our study were opposite for the two groups. This may be indicative of experience-related processing mechanisms associated with expert advantage within their domain of expertise. Table tennis novices have fewer hand-related representations that they can use to simultaneously complete the action anticipation and memory tasks in the three interference conditions. Therefore, novices were monitoring for conflict to a greater extent when they tried to predict hand-related action outcomes in the hand-interference condition than in the leg-interference condition because both table tennis serves and hand-related verbs involve hand-related representation. For experts, the observed decrease in the N2 amplitude in the hand-interference condition suggests that this may be the result of more efficient conflict monitoring as a consequence of more allocated cognitive resources to simultaneous action and word processing in the dual task (Kousaie & Phillips, 2012, 2017).

In conclusion, the current investigation provided support for a link from the language system to the motor system. Linguistic stimuli interfered with the anticipatory judgment of the trajectory of the ball after a table tennis serve, and the interference was more specific to the effector type in table tennis experts than in novices. To our knowledge, no previous study has examined the role that the language system plays in action anticipation by using a dual task involving action and action-related words based on the attentional capacity model and by providing electrophysiological evidence. The findings presented here also support our previous neuroimaging results showing semantic brain regions engaged in action anticipation (Wang, Lu, Deng, Gu, & Zhou, 2019).

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Declarations of interest

The authors declared that there is no conflict of interest.

Table 1. Experiment 1 Participant Demographic and Training Characteristics

Characteristic	**Experts**	**Novices**
Number	33	35
Sex, (No. males/females)	15/18	17/18
Age, mean ± SD, y	19.57 ± 1.51	20.35 ± 1.62
Years of training, mean ± SD	12.06 ± 2.07	none
Training frequency (No. of sessions/week)	12	none
Training time (h/session)	2	none

Table 2. Psycholinguistic properties of the hand- and leg-related words (mean ± standard deviation)

Psycholinguistic feature	Hand-related words	Leg-related words	*z score*	*p value*
Valence	3.02 ± 0.59	2.99 ± 0.75	−0.022	0.983
Arousal	3.11 ± 0.41	3.18 ± 0.40	−0.712	0.476
Imageability	4.40 ± 0.89	4.40 ± 1.25	−0.127	0.899
Word frequency	3.30 ± 1.39	3.07 ± 1.23	−0.769	0.442
Hand relatedness	4.60 ± 0.72	2.50 ± 1.36	-4.234^{**}	< 0.001
Leg relatedness	1.93 ± 1.11	4.83 ± 0.59	-4.769^{**}	< 0.001

Note: The differences in valence, arousal, imageability, word frequency, hand relatedness, and leg relatedness between hand-related words and leg-related words were assessed using the Wilcoxon signed rank test. $^{**}p < 0.01$.

Figure captions

Figure 1 - The procedure showing example trials for the four conditions: control, hand interference, leg interference, and spatial interference. Participants were required to respond twice in the three interference conditions: once for action anticipation (yellow squares) and once for word or spatial recognition (green squares). The plus symbol indicates the start of each trial. Chinese symbols shown are for knit (编织), clap (拍手), chop (切菜), stir (搅拌), stamp (跺脚), skip (跳跃), kick (踢球), and limp (跛行).

Figure 2 - Mean accuracy (in percent) in the control (C), hand-related (H), leg-related (L), and spatial-related (S) interference conditions for expert and novice groups. Bars represent standard error of the mean. $^{*}p < 0.05$ vs. S; $^{**}p < 0.01$ vs. H, L, or S.

Figure 3 - Exemplar frames of videos with congruent action and with incongruent action. A single table tennis player qualified as a National Player of the First Grade served the ball in each video. The difference between the congruent and incongruent videos occurred immediately after the racket contacted the ball (17th frame), with the direction of the body kinematics and ball trajectory being either matched (congruent) or mismatched (incongruent).

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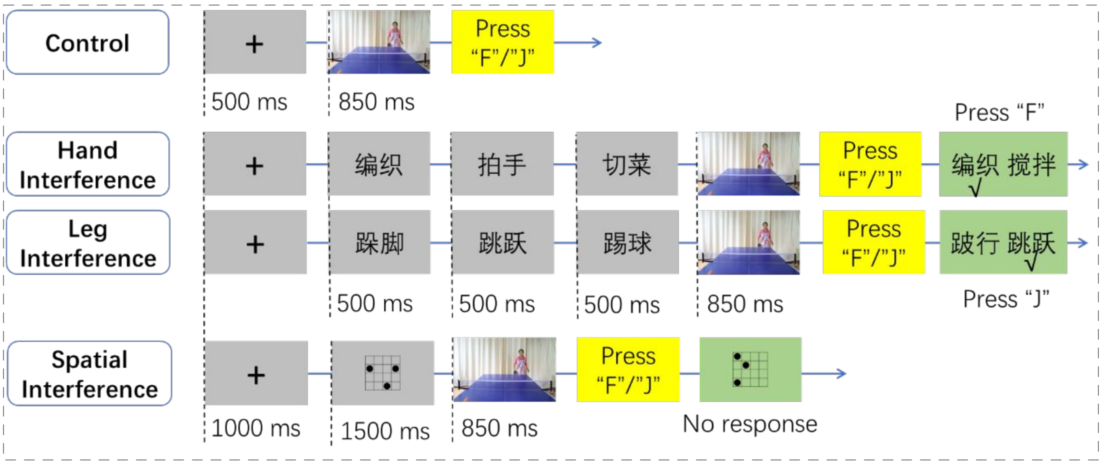

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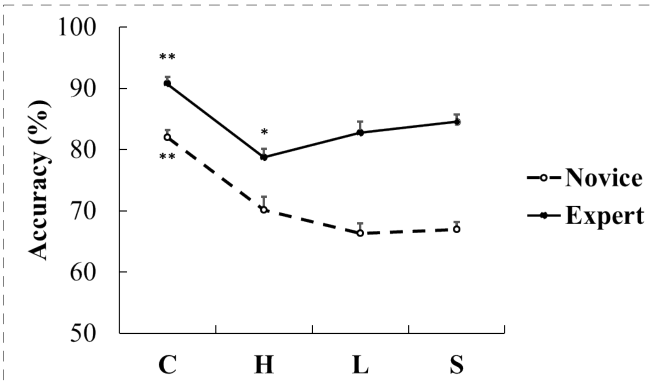

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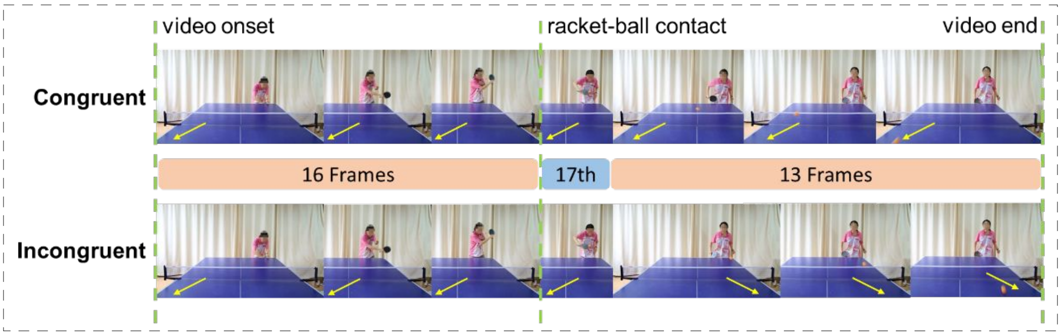

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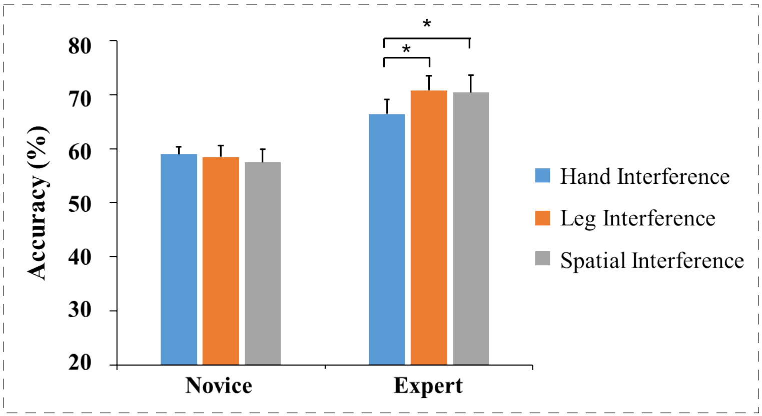

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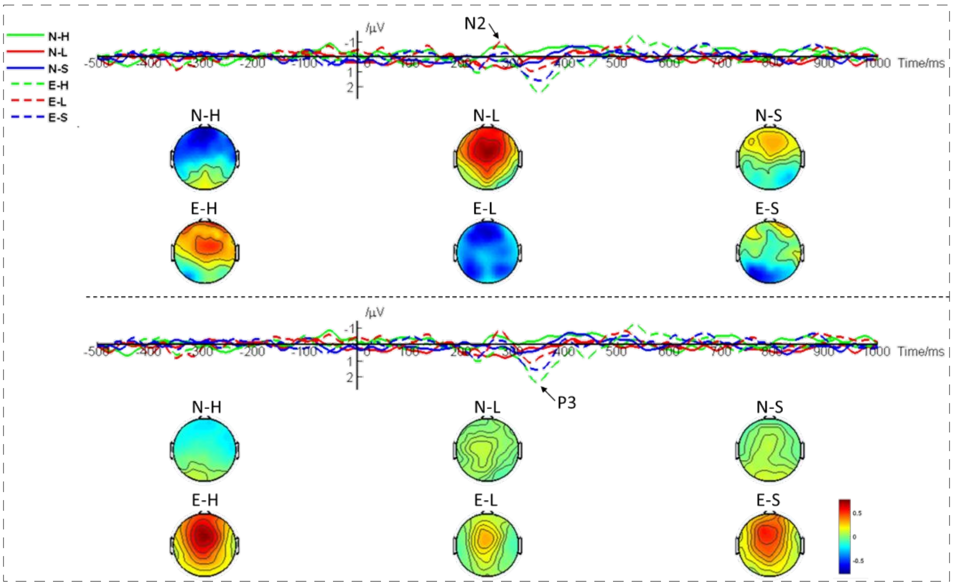

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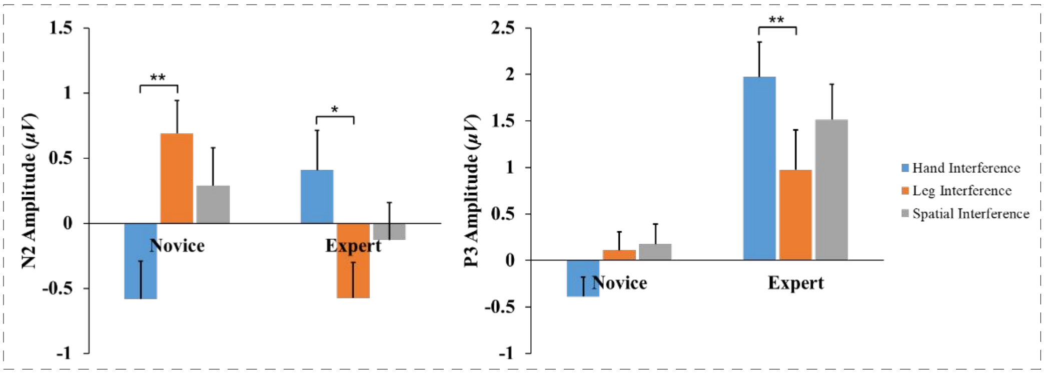

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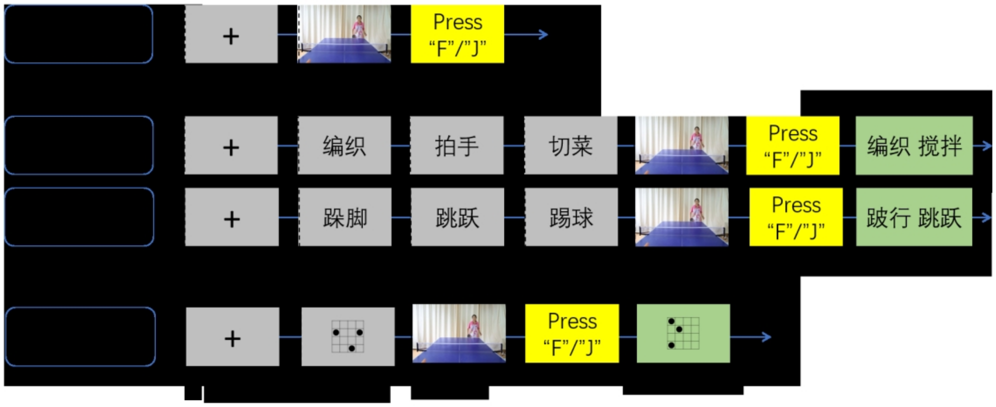

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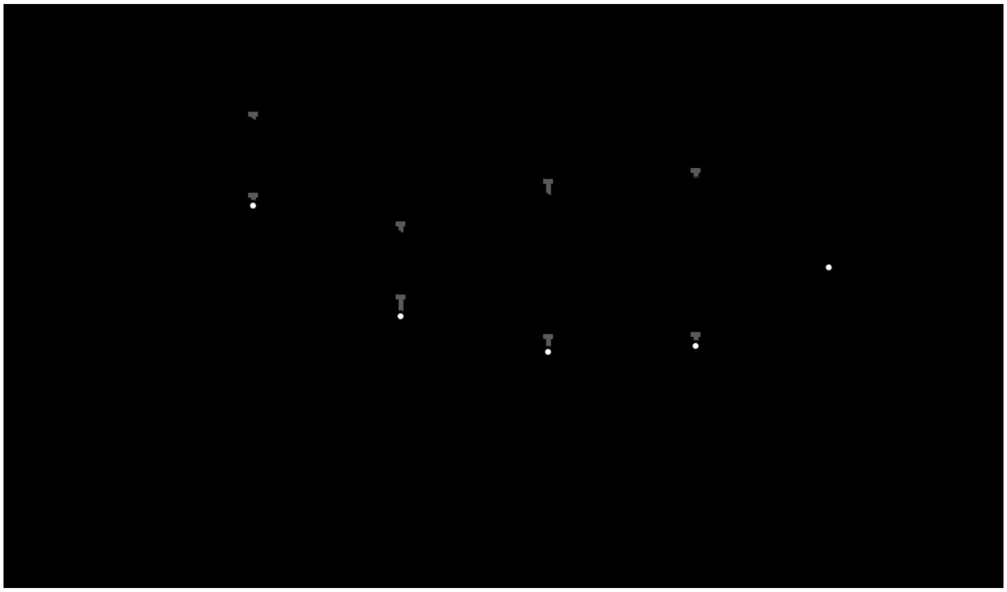

Figure 2. Mean accuracy (in percent) in the control (C), hand-related (H), leg-related (L), and spatial-related (S) interference conditions for expert and novice groups. Bars represent standard error of the mean. *p < 0.05 vs. S; **p < 0.01 vs. H, L, or S.

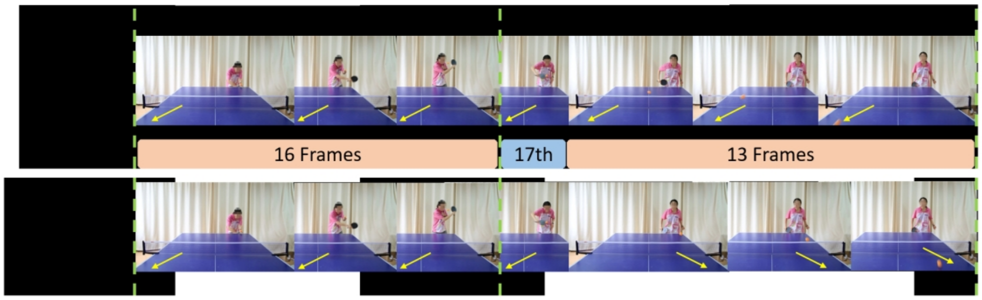

Figure 3. Exemplar frames of videos with congruent action and with incongruent action. A single table tennis player qualified as a National Player of the First Grade served the ball in each video. The difference between the congruent and incongruent videos occurred immediately after the racket contacted the ball (17th frame), with the direction of the body kinematics and ball trajectory being either matched (congruent) or mismatched (incongruent).

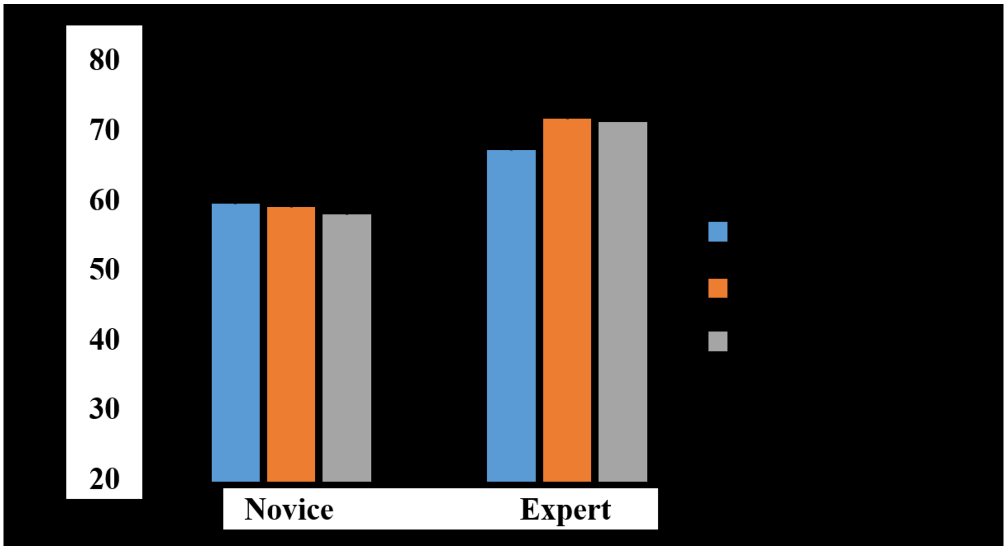

Figure 4. Mean accuracy of the hand-, leg- and spatial-interference conditions in the expert and novice groups. Error bars represent standard error of the mean.*p < 0.05 between the conditions indicated.

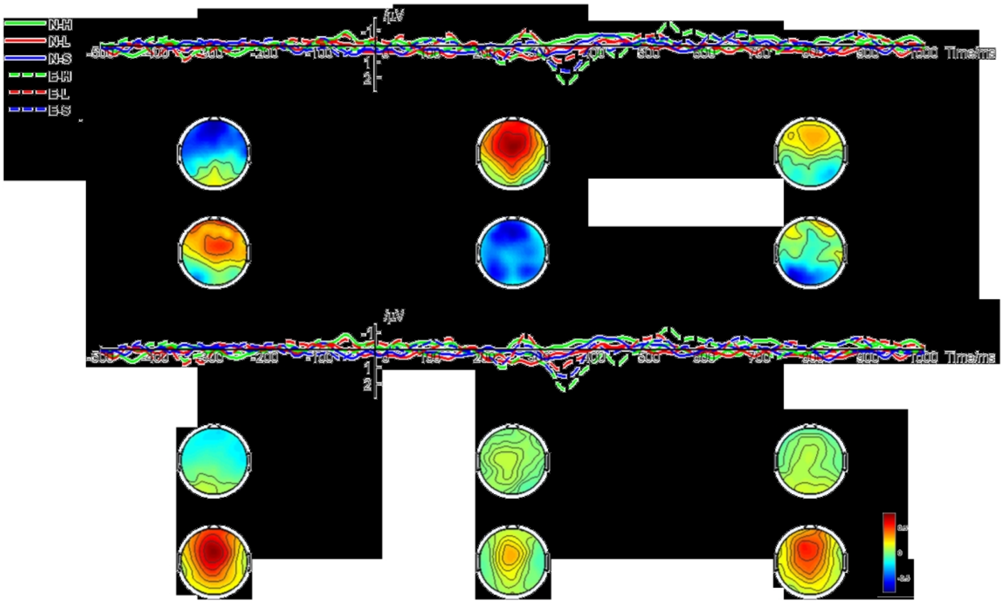

Figure 5. The grand-averaged event-related potentials elicited by the frame of racket-ball contact in the videos at the FCz and the scalp topography reflect the distribution of the N2 component (upper panel) and P3 component (lower panel). N-H represents novice hand-interference condition; N-L, novice leg-interference condition; N-S, novice spatial-interference condition; E-H, expert hand-interference condition; E-L, expert leg-interference condition; E-S, expert spatial-interference condition.

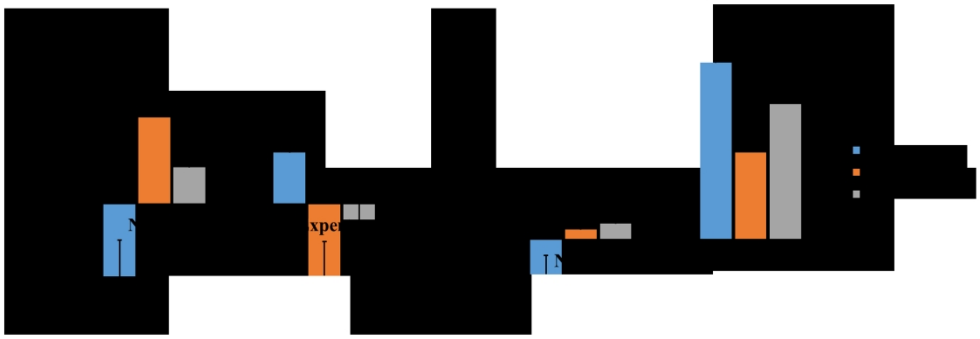

Figure 6. The N2 and P3 amplitudes in response to the three experimental conditions (hand interference, leg interference and spatial interference) in both groups (novice and expert). *p < 0.05 and **p < 0.01 between the conditions indicated.