Conflicts Processing among Multiple Frames of Reference: An ERP Study

Weizhi Nan (nanwz@psych.ac.cn) [a, b, c]
Yanlong Sun (ysun@medicine.tamhsc.edu) [c]
Hongbin Wang (hwang@medicine.tamhsc.edu) [c]
Qi Li (liqi@psych.ac.cn) [a, b]
Xun Liu (liux@psych.ac.cn) [a, b]
[a] CAS Key Laboratory of Behavioral Science, Institute of Psychology, 16 Lincui Road, Chaoyang District, Beijing 100101, China
[b] Department of Psychology, University of Chinese Academy of Sciences, China
[c] Center for Biomedical Informatics, Texas A&M University Health Science Center,
2121 West Holcombe Blvd, Houston, TX 77030, USA

Abstract

People rely on various frames of reference (FORs), such as egocentric (EFOR) and intrinsic (IFOR), to represent spatial information. The present study examined electroencephalogram profiles on a two-cannon task, which could regulate the conflict of IFOR-IFOR (red cannon, blue cannon) and IFOR-EFOR (target cannon, observer), to elucidate the brain mechanisms of FOR conflict processing by using event-related potentials (ERPs). Results showed that both of the conflicts occurred in the reaction time (RT) and there was an interaction between them. ERP results showed more negative amplitudes on N2 (276-326 ms) and P3 (396-726 ms) for IFOR-IFOR conflict of the 180° cannon angle condition and EFOR-IFOR conflict of the target cannon point-down condition. What's more, there was also an interaction between these two conflicts on the P3 amplitudes (561-726 ms). In summary, our findings shed new light on the domain-specific conflict monitoring and domain-general executive control for the IFOR-IFOR and EFOR-IFOR conflicts.

Keywords: frame of reference; conflict monitoring; executive control; parallel process; N2; P3;

Introduction

People adopt multiple frames of reference (FORs) to represent the spatial relationship of objects in a complex environment (Sun & Wang, 2014). Based on the relationship with the observer, FORs can be classified into three types, egocentric FOR (EFOR), intrinsic FOR (IFOR) and allocentric FOR (AFOR) (Mou & McNamara, 2002; Tamborello, Sun, & Wang, 2012). An EFOR-based representation is anchored to the observer, which needs to be updated following the movement of the observer's eye, head, body coordinates (Wang, Johnson, & Zhang, 2001). In an IFOR-based representation, an object or an object group in the viewing environment but exogenous to the observer is used as the reference point. For example, a car is used as an IFOR anchor in the description "the cat is in front of the car". IFORs remain stable with the observer's movement but have to be updated when the reference object moves. In an AFOR-based representation, the entire environment, such as a room or a city, is taken as the reference point. For a comprehensive review, see (Mou, Fan, McNamara, & Owen, 2008; Mou & McNamara, 2002; Sun & Wang, 2010, 2014; Tamborello et al., 2012; Yamamoto & Philbeck, 2013).

"Frame of Reference-based Map of Salience" theory (FORMS) states the human brain represents spatial information simultaneously using multiple FORs, all FORs consist of a FOR map of different salience, and human performance is determined by the interaction of all relevant FOR-based representations (Itti & Koch, 2000; Sun & Wang, 2010, 2014; Tamborello et al., 2012; Wang et al., 2001; Wang, Sun, Johnson, & Yuan, 2005).

If different FORs generate different responses for one target, conflict may occur which requires cognitive control to solve it (Chen, Weidner, Weiss, Marshall, & Fink, 2012; Nan, Li, Sun, Wang, & Liu, in press; Sun & Wang, 2014; Tamborello et al., 2012). According to the different kinds of FORs in the map (one EFOR, one AFOR, multiple IFORs), we could categorize the conflict of FORs as four types: EFOR-AFOR, EFOR-IFOR, AFOR-IFOR, and IFOR-IFOR. Plenty of studies has demonstrated that there exists the conflict of EFOR-AFOR (Chen et al., 2012; Conson, Mazzarella, Donnarumma, & Trojano, 2012; Zhang et al., 2014), EFOR-IFOR (Wang et al., 2005). In addition, previous studies also showed the process of EFOR and AFOR were in parallel. EFOR has high salience and is almost processed automatically that needs little cognitive resource; EFOR is represented and processed in the dorsal visual stream subserving goal-directed actions. AFOR has low salience and needs more cognitive resource to process. AFOR is represented and processed in the ventral visual stream subserving the conscious perception of objects or spatial memory function (Goodale & Milner, 1992; Zhang et al., 2014).

However, does it also exist a conflict of IFOR-IFOR and AFOR-IFOR? There were rare studies focusing on this question. If yes, how does our brain process and solve all these conflicts of different FORs (IFOR-IFOR, EFOR-IFOR, EFOR-AFOR, AFOR-IFOR)? What's more, in view of the limit cognitive resource, is the process of the multiple IFORs also in parallel as same as the process of EFOR and AFOR, or just in serial? If the process is in serial, only one IFOR could be represented and processed, so we could only observe the EFOR-IFOR conflict. Mou et al.(2002, 2008) found that people got higher accuracy for recalling spatial objects' locations represented by IFOR than that represented by EFOR, this means that people might prefer to use IFOR to represent the environment, so IFOR might not need much cognitive resource. According to this, the process of multiple IFORs might be in parallel, different IFORs could be represented and processed, so we could observe the IFOR-IFOR conflict and the interaction among IFOR-IFOR conflict and the EFOR-IFOR conflict.

Following these questions and hypothesis, we developed a two-cannon task (see Figure 1) which could manipulate the EFOR-IFOR and IFOR-IFOR conflicts (Nan et al., in press; Tamborello et al., 2012). The EFOR-IFOR conflict was examined by the target cannon orientation (congruent condition: target cannon pointed-up, incongruent condition: target cannon pointed-down). The IFOR-IFOR conflict was examined by the cannon angle (congruent condition: 0° cannon angle, incongruent condition: 180° cannon angle). The behavioral studies' results showed that the IFOR-IFOR and EFOR-IFOR conflicts (RTs of the incongruent conditions were longer than that of the congruent conditions), and there was an interaction between these two conflicts. The cannon angle effect supported the hypothesis

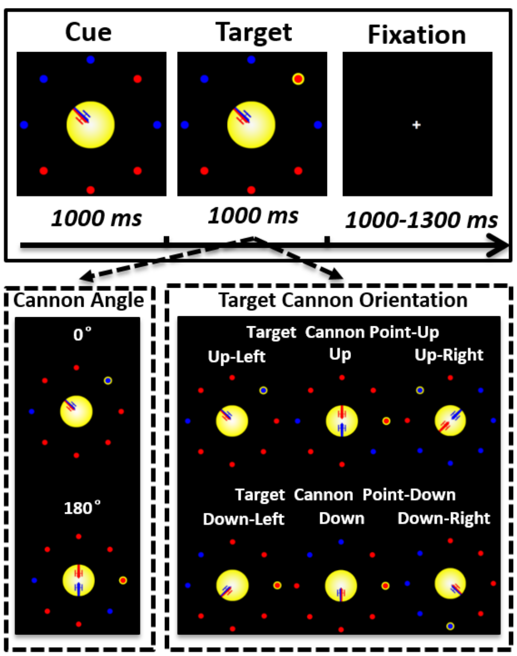

Figure 1. A schematic illustration of the two-cannon task. At the beginning of each trial, a stimulus with two cannons (one blue and one red) and eight pellets (in either blue or red) was presented on the computer screen for 1000 ms, then the target would flash a yellow ring for 1000 ms, participants were asked to press two buttons in the keyboard to rotate the target cannon (with the same color of the target) to the target in the least distance, as quickly as possible. Cannon angle (0°,180°) was designed to test the conflict of IFOR-IFOR, target cannon orientation (target cannon point-up: the combination of target cannon points up-left, up, and up-right conditions; target cannon point-down: the combination of target cannon points down-left, down, and down-right conditions) was designed to test the conflict of EFOR-IFOR.

that there existed the IFOR-IFOR conflict. The target cannon orientation effect supported the hypothesis that there existed the EFOR-IFOR conflict. The interaction between two conflicts supported the hypothesis that the process of different IFORs was in parallel which the two conflicts would be interactive at the late response-selection stage. In summary, the behavioral results suggested that our brain might use a shared conflict processing mechanism for the IFOR-IFOR and EFOR-IFOR conflicts.

However, how does the conflict processing mechanism work at the neural level? Are they just process by the same conflict processing mechanism or by distinct conflict processing mechanisms? The event-related potential (ERP) has a high temporal resolution at the millisecond scale and could more directly reveal the brain activities of the cognitive process, so it is an excellent index to examine the neural mechanism of the FORs conflict processing (Luck, 2014). For the conflict processing, increasing electroencephalogram (EEG) evidence has demonstrated that the conflict-related N2 component which occurs approximately 250–350 ms after stimulus presentation is an effective indicator (Folstein & Van Petten, 2008). The N2 amplitude is thought to index the degree of conflict, with its amplitude increasing as a function of conflict levels (Li et al., 2015). P3 was also typically reported to reflect ERP modulation of conflict process (Frühholz, Godde, Finke, & Herrmann, 2011; Wang, Li, Zheng, Wang, & Liu, 2014).

By applied the ERP to the two-cannon task, we expected to find the neural evidence of the conflict processing among different FORs (EFOR-IFOR, IFOR-IFOR), the parallel process of multiple IFORs and clarified the conflict processing among multiple FORs. Our expectation was that, for the behavioral results, we could replicate our previous behavioral studies' results (Nan et al., in press; Tamborello et al., 2012), which was that RT and error rates (ERR) were larger in the incongruent conditions of the EFOR-IFOR and IFOR-IFOR conflicts and there was also an interaction between them. For the ERP results, the N2 and P3 results could help to reveal the shared or distinct conflict processing mechanism of multiple FORs more clearly. We expected that the amplitude of N2 and P3 would be more negative in the incongruent conditions of the two conflicts and there was also an interaction between them.

Method

Participants

Twenty undergraduate students (18–29 years old, average 22.8 years old, 6 women) participated in the present EEG experiment. All participants reported that they had no neurological or psychiatric history. All participants were right-handed and had normal or corrected-to-normal vision. Each participant voluntarily enrolled and signed an informed consent form prior to the experiments. This study was approved by the Institute of Psychology, Chinese Academy of Sciences.

Procedures

Participants were seated comfortably in a dimly lit and sound-attenuating chamber approximately 80 cm away from a computer screen (resolution, 1024×768 pixels, vertical refresh rate, 75 Hz). Stimulus presentation and manual response measurement were controlled by E-Prime 2.0 (Psychological Software Tools, Inc., Pittsburgh, PA, USA).

Each trial began with two cannons surrounding eight colored dots for 1000 ms. Then, the target pellet was marked by a yellow ring for 1000 ms. Participants were instructed to press a button on the keyboard (left-"z" for counter-clockwise or right-"/" for clockwise), as quickly and accurately as possible, to rotate the target cannon (the one with the same color as the target pellet) to shoot the target in the least distance. After the target disappeared, a fixation cross was presented at the center of the screen for 1000-1300 ms.

EEG Recordings and Offline Processing

The EEG was recorded from 64 scalp sites using Ag/AgCl electrodes arranged in an elastic cap according to an extension of the International 10-20 system (NeuroScan Inc., Herndon, VA). Vertical eye movements were recorded by two positioned above and below the left eye. The horizontal electrooculogram was recorded using lateral electrodes from both eyes. Impedances were below 5 kΩ for all recording sites. EEG signals were amplified using a NeuroScan SymAmps2 amplifier with a band-pass of 0.05 – 100 Hz and sampled with 500 Hz.

All scalp electrodes were referenced to the left mastoid online and were referenced to the average of the left and right mastoids offline. Each epoch started from 200 ms before the onset of the stimulus and lasted 800 ms, with the first 200 ms as the baseline. Trials with errors or trials that were contaminated with artifacts exceeding ± 100 μV were excluded from the analysis. The data were averaged for each condition and then digitally low-pass filtered at 30 Hz (24 dB/octave) with zero phase shift.

Statistical Analysis

Behavioral Data Analysis

Repeated-measures ANOVA and paired-sample t-test were performed on reaction times (RTs) of correct responses and error rates (ERs) and evaluated at $p < .05$. Trials with errors or with RT beyond three standard deviations were excluded from the RT analysis. A repeated-measures ANOVA was conducted for cannon angle effect and target cannon orientation effect (Figure. 2 B and Table 2), in which the 2 × 2 factors tested were cannon angle (0°, 180°) and target cannon orientation (up, down). Bonferroni correction was used for pair-wise comparisons.

ERP Data Analysis

The ERPs of correct responses were averaged for each condition. The time window for N2 and P3 was identified using the following protocol. First, we detected the peak latencies of all conditions at the midline electrodes (Fz, FCz, Cz, CPz, and Pz) and calculated the mean of these latencies for N2 (301 ms) and P3 (561 ms). For the N2 and P3 components, 50-ms and 330-ms time windows were centered on the mean peak latency, respectively. Therefore, the cannon angle effect and target cannon orientation effect were analyzed within 276-326 ms on N2 mean amplitude and within 396-561 and 561-726 ms on P3 mean amplitude after stimulus onset.

Separated repeated-measures ANOVAs were performed on the mean N2 and the two time windows of mean P3, respectively. The factors cannon angle (0° and 180°), target cannon orientation (up and down) and electrode (Fz, FCz, Cz, CPz, and Pz) were used to search for cannon angle effect and target cannon orientation effect. The significance level was set at $\alpha < .05$ for all ANOVAs. The mean number of trials retained for each condition are listed in the trial number of Table 1. A two-way analysis of variance (ANOVA) was calculated for the trial numbers of cannon angle and target cannon orientation, results showed there were no significant differences among them. The main effect of cannon angle: $F(1, 19) = 1.19$, $p > .05$, the main effect of target cannon orientation: $F(1, 19) = 1.17$, $p > .05$, the interaction between them: $F(1, 19) = 0.18$, $p > .05$. These analysis results eliminated the potential influence of different signal-noise ratios to statistical comparison.

Results

RTs and ERs

Regarding RTs (Figure 2 and Table 1), there was a significant main effect of target cannon orientation, $F(1, 19) = 256.74$, $p < .001$, $\eta_p^2 = .93$, indicating that the RT in the target cannon point-down condition (697 ± 24 ms) was longer than that in the target cannon point-up condition (619 ± 22 ms). There was a main effect of cannon angle, $F(1, 19) = 50.43$, $p < .001$, $\eta_p^2 = .73$, indicating that the RT in the 0° cannon angle condition (558 ± 24 ms) was shorter than that in the 180° cannon angle condition (756 ± 22 ms). The interaction of the two factors was also significant, $F(1, 19) = 6.48$, $p < .05$, $\eta_p^2 = .25$. Post-hoc analysis showed that target cannon orientation effect in the 180° condition (89 ± 13 ms) was larger than target cannon orientation effect in the 0° condition (68 ± 11 ms), $t\ (1, 19) = 2.55$, $p < .05$.

ERs showed significant a main effect for target cannon orientation, $F(1, 19) = 22.54$, $p < .001$, $\eta_p^2 = .54$, indicating that the ER in the target cannon point-down condition (7.7 ± 1.1%) was larger than that in the target cannon point-up condition (3.0 ± 0.7%). The main effect of cannon angle and the interaction of the two factors were not significant.

N2 and P3

Regarding EFPs (see Figure 3), for N2, there was a significant main effect of target cannon orientation $F(1, 19) = 4.88$, $p < .05$, $\eta_p^2 = .20$, with more negative N2 amplitudes

Table 1 RTs and ERs for target cannon orientation and cannon angle

Target cannon orientation	Cannon angle					
	RT(ms)		ER(%)		Trial number	
	0°	180°	0°	180°	0°	180°
Down	592±25	802±24	7.1±1.3	8.2±1.1	141±7	147±5
Up	524±23	713±22	2.5±0.8	3.6±0.7	144±7	150±6

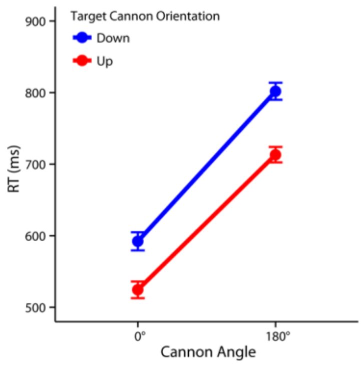

Figure 2. RT of target cannon orientation effect and cannon angle effect. RT of the target cannon point-down condition was longer than that of the target cannon point-down condition; RT of the 180° cannon angle condition was longer than that of 0° cannon angle condition. The effect size of target cannon orientation effect in the 180° cannon angle condition was larger than that in the 0° cannon angle condition.

to the target cannon point-down condition (0.27 ± 0.76 µV) than to the target cannon point-up condition (0.83 ± 0.76 µV). There was a marginally significant main effect of target cannon orientation, $F(1, 19) = 3.51$, $p = .076$, $\eta_p^2 = .16$, with more negative N2 amplitudes to the 180° cannon angle condition (0.02 ± 0.68 µV) than to the 0° cannon angle condition (1.07 ± 0.791 µV). There was a marginally significant interaction between cannon angle and electrode, $F(4, 76) = 3.27$, $p = .057$, $\eta_p^2 = .15$, post-hoc analysis showed that the cannon angle effect was significant at FCz and Cz, *ps* < .05, revealed that the N2 in the 180° cannon angle condition (FCz: -0.38 ± 0.78 µV, Cz: -0.18 ± 0.81 µV) was more negative than that in the 0° cannon angle condition (FCz: 1.01 ± 0.98 µV, Cz: 1.21 ± 1.07 µV). There were no other significant effects obtained.

For the first time window of P3 (396-561 ms), there was a significant main effect of cannon angle, $F(1, 19) = 15.39$, $p < .01$, $\eta_p^2 = .45$, with more positive P3 amplitudes to the 0° cannon angle condition (2.07 ± 0.81 µV) than to the 180° cannon angle condition (-0.20 ± 0.65 µV). There was a significant main effect of target cannon orientation, $F(1, 19) = 20.74$, $p < .001$, $\eta_p^2 = .52$, with more positive P3 amplitudes to the target cannon point-up condition (1.47 ± 0.69 µV) than to the target cannon point-down condition (0.40 ± 0.69 µV). There was a significant main effect of

electrode, $F(4, 76) = 24.01$, $p < .001$, $\eta_p^2 = .56$, with more positive P3 amplitudes at Cz, CPz, and Pz compared with Fz and FCz (*ps* < . 001). There was a significant interaction between cannon angle and electrode, $F(4, 76) = 7.42$, $p < .01$, $\eta_p^2 = .28$, post-hoc analysis showed that the cannon angle effect was significant at five electrodes, *ps* < .01, and the largest difference was at FCz (3.04 ± 0.74 µV). There was a significant interaction between target cannon orientation and electrode, $F(4, 76) = 5.42$, $p < .01$, $\eta_p^2 = .22$, post-hoc analysis showed that the target cannon orientation effect was significant at five electrodes, *ps* < .01, and the largest difference was at FCz (1.36 ± 0.30 µV). No other significant effects were obtained.

For the second time window of P3 (561-726 ms), there was a significant main effect of cannon angle, $F(1, 19) = 14.90$, $p < .01$, $\eta_p^2 = .44$, with more positive P3 amplitudes to the 0° cannon angle condition (1.91±0.64 µV) than to the 180° cannon angle condition (0.15 ± 0.64 µV). There was a significant main effect of target cannon orientation, $F(1, 19) = 29.29$, $p < .001$, $\eta_p^2 = .61$, with more positive P3 amplitudes to the target cannon point-up condition (1.68 ±0.59 µV) than to the target cannon point-down condition (0.38 ± 0.62 µV). There was a significant main effect of electrode, $F(4, 76) = 7.54$, $p < .01$, $\eta_p^2 = .28$, with more positive P3 amplitudes at Cz, CPz compared with Fz and FCz (*ps* < .05). There was a significant interaction between

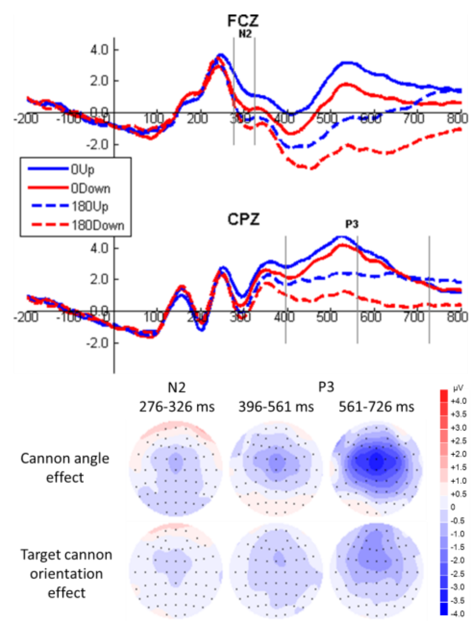

Figure 3. Grand-average ERP results. A. N2 activity at FCz and P3 activity at CPz for cannon angle effect and target cannon orientation effect. B. the topography maps of the difference waveforms of cannon angle effect and target cannon orientation effect.

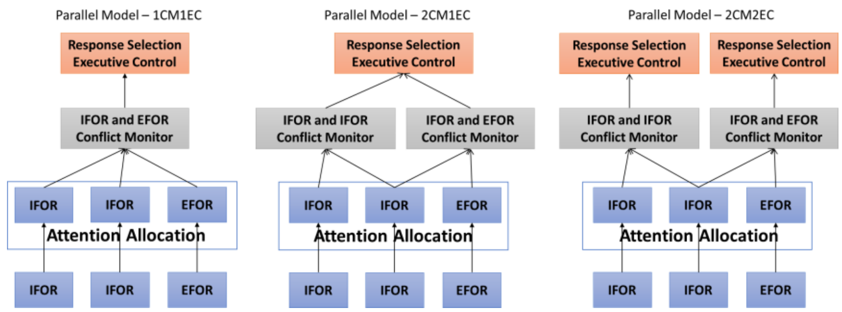

Figure 4. Three kinds of FOR conflict processing models. The three kinds of models are all parallel models. All of them showed the IFORs could be represented and processed in parallel that generates two conflicts of IFOR-IFOR and EFOR-IFOR. The difference is whether there are specific or shared conflict monitoring module and executive control module. The parallel model (1CM1EC) showed that there was only one conflict monitoring module (CM) and one executive control module (EC) for both conflicts. The parallel model (2CM1EC) showed that there were two conflict monitoring modules for each conflict and only one executive control module for both conflicts. The parallel model (2CM2EC) showed that there were two conflict monitoring modules and two executive control modules for each conflict.

cannon angle and electrode, $F(4, 76) = 5.96$, $p < .05$, $\eta_p^2 = .24$, post-hoc analysis showed that the cannon angle effect was significant at five electrodes, *ps* < .01, and the largest difference was at FCz (3.04 ± 0.74 µV). There was a significant interaction between target cannon orientation and electrode, $F(4, 76) = 16.52$, $p < .001$, $\eta_p^2 = .47$, post-hoc analysis showed that the target cannon orientation effect was significant at five electrodes, *ps* < .05, and the largest difference was at FCz (2.53 ± 0.60 µV). Most interesting, there was a significant interaction between cannon angle and target cannon orientation, $F(1, 19) = 4.56$, $p < .05$, $\eta_p^2 = .19$, post-hoc analysis showed that target cannon orientation effect in the 180° cannon angle condition (1.93 ± 0.40 µV) increased and was significant compared to that in the 0° cannon angle condition (0.67 ± 0.36 µV). No other significant interactions were obtained.

Discussion

Overall, the findings of the present study suggested that EFOR-IFOR and IFOR-IFOR conflicts had specific neural correlates and the process of IFORs was in parallel.

First, behavioral data showed the conflicts of EFOR-IFOR and IFOR-IFOR, the interaction between them. Second, the ERP results showed that the independent cannon angle effect and target cannon orientation effect on the N2 amplitudes, from 276 to 326 ms, which indicated the independent conflict monitoring modules for the conflicts of EFOR-IFOR and IFOR-IFOR. What's more, the two effects interacted on the P3 amplitudes, from 561 to 726 ms, which indicated the shared executive control module for the two conflicts.

Yang, Nan, Li, and Liu (2015) used stimulus-response compatible tasks to collect behavioral and ERP data to support the 2CM1EC model (two domain-specific conflict monitoring modules and one domain-general executive control module for the conflicts of stimulus-stimulus and stimulus-response) of cognitive control for conflict processing, compared to the 1CM1EC model and 2CM2EC model. For a comprehensive review, see (Li, Nan, Wang, & Liu, 2014; Li et al., 2015; Liu, Nan, Wang, & Li, 2013; Liu, Park, Gu, & Fan, 2010; Wang et al., 2014; Yang et al., 2015).

On the spatial cognition area, we also could hypothesize three kinds of model for the conflict processing among different FORs (1CM1EC, 2CM1EC, and 2CM2EC, see Figure 4). 1CM1EC model shows there is only one general conflict monitoring module and one executive control for conflicts of EFOR-IFOR and IFOR-IFOR. The 2CM1EC model shows there are two specific conflict monitoring modules for conflicts of EFOR-IFOR and IFOR-IFOR, and one general executive control module for the two conflicts. The 2CM2EC model shows there are two specific conflict monitoring modules and two specific executive control modules for the two conflicts.

In our task, the behavioral results showed the cannon angle effect (conflict of IFOR-IFOR), target cannon orientation effect (conflict of EFOR-IFOR) and the interaction between them, which supported that the parallel process of the IFORs and the shared conflict process mechanism at the behavioral level. The ERP results showed the independent cannon angle effect and target cannon orientation effect on the N2 amplitudes, which further suggests there might be two specific conflict monitoring modules for the conflicts of EFOR-IFOR and IFOR-IFOR at the neural level. What's more, we also found the two effects , and the interaction between them on the P3 amplitudes. This suggests there might be only one shared executive control module for these conflicts at the neural level. In summary, our results supported the 2CM1EC model for the cognitive control of spatial conflict processing.

In the current two-cannon task, the AFOR is anchored on the computer screen which has the same direction (point-up) with the EFOR, so we could not separate the conflict of AFOR-IFOR and EFOR-IFOR. In the future, we could try to manipulate the AFOR and observe the interaction of all kinds of conflict which could be more comprehensive understand the spatial conflicts processing of FORs.

Conclusion

Our task replicated the previous behavioral results well. What's more, the ERP results showed that common and distinct electrophysiological correlates for EFOR-IFOR and IFOR-IFOR conflict processing. On the one hand, EFOR-IFOR and IFOR-IFOR have domain-specific conflict monitoring modules, as revealed by the independent N2 component. On the other hand, both of them share a domain-general executive control module, as revealed by the interaction of P3 component. The conflict of IFOR-IFOR and the interaction of EFOR-IFOR and IFOR-IFOR also suggest that the process of different IFORs is in parallel.`

Acknowledgments

This work was partially supported by a Natural Science Foundation of China grant (31328013), an Air Force Office of Scientific Research (AFOSR) grant (FA9550-12-1-0457), and an Office of Naval Research (ONR) grant (N00014-16-1-2111).

References

Chen, Q., Weidner, R., Weiss, P. H., Marshall, J. C., & Fink, G. R. (2012). Neural interaction between spatial domain and spatial reference frame in parietal–occipital junction. *Journal of Cognitive Neuroscience, 24*(11), 2223-2236. doi:2210.1162/jocn_a_00260.

Conson, M., Mazzarella, E., Donnarumma, C., & Trojano, L. (2012). Judging hand laterality from my or your point of view: interactions between motor imagery and visual perspective. *Neuroscience Letters, 530*(1), 35-40.

Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology, 45*(1), 152-170.

Frühholz, S., Godde, B., Finke, M., & Herrmann, M. (2011). Spatio-temporal brain dynamics in a combined stimulus–stimulus and stimulus–response conflict task. *Neuroimage, 54*(1), 622-634.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in neurosciences, 15*(1), 20-25.

Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Res, 40*(10-12), 1489-1506.

Li, Q., Nan, W., Wang, K., & Liu, X. (2014). Independent Processing of Stimulus-Stimulus and Stimulus-Response Conflicts. *Plos One, 9*(2), e89249.

Li, Q., Wang, K., Nan, W., Zheng, Y., Wu, H., Wang, H., & Liu, X. (2015). Electrophysiological dynamics reveal distinct processing of stimulus-stimulus and stimulus-response conflicts. *Psychophysiology, 52*(4), 562-571.

Liu, X., Nan, W., Wang, K., & Li, Q. (2013). Modular Organization of Cognitive Control. *Advances in Psychological Science, 21*(12), 2091-2102.

Liu, X., Park, Y., Gu, X., & Fan, J. (2010). Dimensional overlap accounts for independence and integration of stimulus-response compatibility effects. *Atten Percept Psychophys, 72*(6), 1710-1720. doi:1710.3758/APP.1772.1716.1710.

Luck, S. J. (2014). *An introduction to the event-related potential technique*: MIT press.

Mou, W., Fan, Y., McNamara, T. P., & Owen, C. B. (2008). Intrinsic frames of reference and egocentric viewpoints in scene recognition. *Cognition, 106*(2), 750-769.

Mou, W., & McNamara, T. P. (2002). Intrinsic frames of reference in spatial memory. *J Exp Psychol Learn Mem Cogn, 28*(1), 162-170.

Nan, W., Li, Q., Sun, Y., Wang, H., & Liu, X. (in press). Conflict Processing among Multiple Frames of Reference. *PsyCh Journal*.

Sun, Y., & Wang, H. (2010). Perception of space by multiple intrinsic frames of reference. *Plos One, 5*(5), e10442.

Sun, Y., & Wang, H. (2014). Insight into others' minds: spatio-temporal representations by intrinsic frame of reference. *Frontiers in Human Neuroscience, 8(58)*, 1-11. doi:10.3389/fnhum.2014.00058.

Tamborello, F. P., 2nd, Sun, Y., & Wang, H. (2012). Spatial reasoning with multiple intrinsic frames of reference. *Experimental Psychology, 59*(1), 3-10.

Wang, H., Johnson, T., & Zhang, J. (2001). *The mind's views of space.* Paper presented at the In Proceedings of the third international conference on cognitive science, Beijing, China.

Wang, H., Sun, Y., Johnson, T. R., & Yuan, Y. (2005). Prioritized spatial updating in the intrinsic frame of reference. *Spatial Cognition and Computation, 5*(1), 89-113. doi:110.1207/s15427633scc15420501_15427634.

Wang, K., Li, Q., Zheng, Y., Wang, H., & Liu, X. (2014). Temporal and spectral profiles of stimulus–stimulus and stimulus–response conflict processing. *Neuroimage, 89*, 280-288.

Yamamoto, N., & Philbeck, J. W. (2013). Intrinsic frames of reference in haptic spatial learning. *Cognition, 129*(2), 447-456.

Yang, G., Nan, W., Li, Q., & Liu, X. (2015). Behavioral and electrophysiological profiles reveal domain-specific conflict processing. *Advances in Computational Psychophysiology*, 33-34.

Zhang, M., Tan, X., Shen, L., Wang, A., Geng, S., & Chen, Q. (2014). Interaction between allocentric and egocentric reference frames in deaf and hearing populations. *Neuropsychologia, 54*, 68-76.