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Conflict monitoring in multi-sensory flanker tasks: Effects of cross-modal distractors on the N2 component

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Abstract

The N2 component is a well-known neural correlate of conflict monitoring (CM), being more negative in the presence of conflicting information in visual conflict tasks. However, whether to-be-ignored auditory distractors can introduce additional conflict remains unknown. In the present work, subjects performed a visual (V) and audiovisual (AV) version of a Go/NoGo flanker task, and responded only if the target arrow pointed toward a pre-specified direction (e.g., left). In the AV task, in which to-be-ignored auditory distractors that were semantically associated with the flankers were concurrently presented, the congruency effect on both RT and N2 amplitude were enhanced, confirming that additional conflict can be brought about by cross-modal distractors at both behavioural and neural levels. Consistent with the hypothesis that N2 amplitude reflects response conflict in visual conflict tasks, within-subject correlation between N2 amplitude and RT was significant in the Go conditions for the V task (congruent/incongruent). However, for the AV task, the correlation was significant only in the congruent condition. These findings suggest that while the cross-modal conflict is registered by the CM process, only part of this conflict could effectively induce response conflict.

1. Introduction

Successful goal-oriented behaviour depends on the functioning of cross-modal selective attention, which enables us to focus our attention on one modality, and filter out irrelevant/conflicting information in unattended modalities. Previous works have extensively studied how conflict processing operates in uni-sensory conflict tasks, e.g., Eriksen's flanker task [1]. The conflict monitoring (CM) theory [2, 3] is especially influential in elucidating the brain network that subserves conflict processing. It hypothesises that the anterior cingulate cortex (ACC) plays a key role to detect conflicts between competing response options (see also [4]). Since its original proposal, the theory has been extended to other aspects of conflict processing, including conflict adaptation [5] and error detection [6]. In event-related potential (ERP) research, the N2 component—a frontocentral component that peaks about 200–350 ms post-stimulus [7]—is known to be an index of conflict monitoring [8]. The N2 amplitude is larger (i.e., more negative) in the presence of response conflict [9, 10]. For example, in Go/NoGo tasks, the N2 amplitude is larger for rare NoGo trials because subjects need to overcome a response tendency induced by frequent Go trials [11, 12]. Similarly, in flanker tasks, it is larger for incongruent than congruent trials, because the incorrect response option is activated involuntarily by the flankers in incongruent trials [12, 13].

To date, there has been little work on whether the CM process is sensitive to cross-modal distractors presented in a to-be-ignored modality. While it is highly plausible that the presence of such cross-modal distractors in a visual

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(V) conflict task would introduce additional interference, results of behavioural studies have been mixed [14, 15, 16]. For example, Elliott et al. [14] compared the congruency effect in three audiovisual (AV) Stroop paradigms with the conventional Stroop task. In these AV paradigms, auditory distractors that either match or mismatch the visual stimuli in colour were simultaneously presented. Compared to the conventional task, the congruency effects were all significantly reduced. The authors suggested that such *reduction* might be due to effects of dilution, i.e., the reduction in interference in the presence of a neutral distractor. However, using a similar stimulus design as Elliott et al. [14], a later work by Francis et al. [15] demonstrated significant *enhancement* in the RT congruency effect, regardless of whether the distracting verbal dimension was embedded within the coloured word target or presented in its vicinity as flankers.

To our knowledge, only one study has examined a similar issue [17]. In this ERP study, subjects made Go responses to the visual word DRÜCK ("press" in German). The NoGo trials were split into three conditions—the visual word STOPP ("stop") was presented concurrently with the spoken word STOPP ("congruent") or DRÜCK ("incongruent"), or in isolation. Despite the effectiveness of cross-modal selective attention, the result revealed a congruency effect on N2 amplitude, confirming that cross-modal distractors can bring about response conflict. However, whether cross-modal distractors remain effective in inducing conflict in the presence of distractors in the attended modality remains unknown.

Another unaddressed issue concerns the functional role of N2 component in AV conflict tasks. In V conflict tasks, a number of works found a within-subject correlation between N2 amplitude and RT [6, 18]—N2 amplitude was larger (i.e., more negative) for trials with slower than faster RT. This provided solid evidence that N2 amplitude primarily reflects the degree of response conflict in V conflict tasks. However, it is known that the ACC is not only sensitive to response conflict but also sensory conflicts [4]—both within-modal [19] and cross-modal [20]. It is plausible that if N2 amplitude in an AV task is a mixture of sensory and response conflicts, the N2–RT correlation may be weakened when compared with V tasks.

The present EEG study employed a flanker paradigm, which has been central in the development of the CM theory, to test whether to-be-ignored cross-modal distractors introduce additional conflict in a visual conflict task. Specifically, we modified the Go/NoGo flanker task used in a recent study (see Table 1 of [21], "inhibition block"), and created a visual (**V**) and audiovisual (**AV**) version of the task. The task of Groom and Cragg [21] was unique in that subjects are only required to respond with the dominant hand. In examining the correlation between N2 amplitude and RT with Go trials, this has the advantage of avoiding complications that arise due to the slower responses by the non-dominant hand.

In the **V** task, subjects were presented with spatial arrays, each comprising a target symbol (left or right arrows) in the middle and flankers that were either the same as (congruent, C) or different from (incongruent, I) the target symbol. They were instructed to ignore the flankers, and respond to the target arrow at the central fixation point only if the arrow pointed toward a pre-specified direction (left/right). This task comprised four critical conditions: for both Go and NoGo trials, the two types of trials (C/I) were presented with equal probability. Neutral trials were also included as fillers, to ensure compatibility with the bulk of the previous works [e.g., 13]. Go trials occurred twice as often as NoGo trials (probability: Go, 67%; NoGo, 33%). Similarly, the **AV** task comprised the same four conditions, except that a word (e.g., left, presented in subjects' native language) that always matched the direction of the flanker was presented aurally and simultaneously with the spatial array.

Comparing the two tasks, we hypothesised that the congruency effect (I minus C) on RT would be significantly greater for **AV** than **V** task. Correspondingly, the congruency effect on N2 amplitude would also be significantly larger (more negative) in the **AV** task. Neutral trials were excluded in testing these two *a priori* hypotheses in order to increase the statistical power. In addition to these main hypotheses, further analyses were conducted to clarify the functional role played by the N2 component, with respect to whether the N2 amplitude reflects response conflict even in an audiovisual scenario. If the additional conflict introduced by to-be-ignored auditory distractors primarily occurs at a response level in the **AV** task, the within-subject N2 amplitude–RT correlation should be similar or even strengthened when compared with that in the **V** task. However, if it instead represents a mixture of sensory and response conflicts, the same correlation should be weakened in the **AV** task. In addition, it remains unknown whether the congruency effect for NoGo conditions is comparable to that for Go conditions. Exploratory analysis focusing on NoGo conditions was therefore conducted to clarify this point.

2. Materials and Methods

2.1. Subjects

Subjects were 28 undergraduates (14 M) between 18 and 25 years ($M = 21.3$, $SD = 2.1$). All of them were right-handed [22], were native Cantonese speakers, had no known neurological disorders, and reported normal hearing and normal/correct-to-normal vision. All procedures were approved by the Ethical Review Committee in the Hong Kong Polytechnic University. Subjects were paid about HKD 100 for their participation. Informed consent was obtained from all subjects.

2.2. Experimental design and data acquisition

Subjects took two Go/NoGo flanker tasks successively—visual (**V**) and audiovisual (**AV**), the order of which was counterbalanced across subjects. In the **V** task, each stimulus array comprised a centrally presented target arrow (< or >) flanked by arrows or plus signs on each side, e.g., <<<<< (C), >><>> (I), or ++<++ (N), and subtended a visual angle of about 5.5°. In the **AV** task, in addition to visual stimuli, auditory distractors corresponding to the flankers' identity were presented simultaneously (Fig. 1). In both tasks, subjects pressed a button with their right index finger only if the target arrow points to a pre-specified direction (e.g., left, <). The proportion of Go to NoGo trials was 2:1, which was comparable to previous works (e.g., [17]). Within both Go and NoGo trials, the three types of trials (C/I/N) were presented with equal probability (0.33). Subjects were given 2000 ms to respond with their right hand as quickly and accurately as possible. There were 432 trials within each task, with 96 and 48 trials for each Go and NoGo condition, respectively. Neutral trials were included as fillers only. During the tasks, electroencephalograms were acquired at 2048 Hz with a 32-channel ActiveTwo EEG system, using Ag/AgCl electrodes. Two electrodes were placed over the two mastoids for offline re-referencing. Horizontal/vertical electroocculograms were recorded by four electrodes placed near the two outer canthi, and above/below left eye. Other details can be found in [23].

2.3. Behavioural data analysis

A pre-planned 2×2 repeated measures ANOVA between Task (**V**/**AV**) and Congruency (C/I) was used to test the *a priori* hypothesis that the RT congruency effect (I minus C) was larger in **AV** than **V** task.

Go/NoGo	Congruency	Abbr.	Critical / Filler	Visual Stimulus	Auditory Stimulus
Go	Congruent	Go-C	Critical	<<<<<	[tʃɔ:˥] /zo2/ “left”
Go	Incongruent	Go-I	Critical	>><>>	[jɐu˨] /jau6/ “right”
Go	Neutral	Go-N	Filler	++<++	[tʃʊŋ˥] /zung1/ “middle”
NoGo	Congruent	NoGo-C	Critical	>>>>>	[jɐu˨] /jau6/ “right”
NoGo	Incongruent	NoGo-I	Critical	<<><<	[tʃɔ:˥] /zo2/ “left”
NoGo	Neutral	NoGo-N	Filler	++>++	[tʃʊŋ˥] /zung1/ “middle”

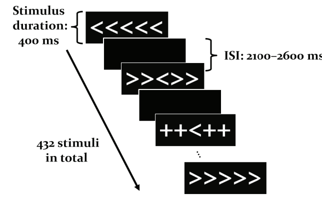

Fig. 1. The Go/NoGo flanker task. Left: Example stimuli for four critical and two filler conditions. The pronunciation of the auditory stimuli, spoken in Cantonese, are shown in International Phonetic Alphabet. In the visual task, only visual stimuli were present. In the audiovisual task, auditory stimuli were presented simultaneously. Note: target direction was left in this illustration. Right: Experimental paradigm used in the present study; stimuli in the six conditions were randomly presented, at an inter-stimulus interval (ISI) of 2100-2600 ms. Each auditory stimulus was 400 ms long, matching the duration of the visual stimulus.

2.4. ERP analysis

Raw EEG data were filtered between 0.1–30 Hz and downsampled to 512 Hz using EEGLAB [24]. Epochs going from -200 ms to 1500 ms with respect to stimulus-onset were obtained. The data were then re-referenced to the average mastoid. Baseline correction was performed using the 200 ms pre-stimulus. Epochs with voltage fluctuation of over 120 μV in any of the remaining (good) electrodes or the two reference electrodes, eye movements (threshold: 120 μV), or blinks (threshold: 200 μV) between -200 ms and 400 ms were excluded. Eye movements and blinks present in the epochs were removed based on independent component analysis [24]. Other details on preprocessing can be found in [23].

For statistical analysis, mean N2 amplitude was computed for Go conditions in the pre-defined window 250–400 ms. Specifically, a three-way repeated measures ANOVA was run for the mean N2 amplitude with the following factors: Task (**V**/**AV**), Congruency (C/I), and Site (Fz/Cz). For the exploratory analysis on NoGo conditions, the same ANOVA was conducted for the mean amplitude at 250–400 ms. However, because the difference waves (I minus C) formed for NoGo conditions peaked at about 400 ms, instead of about 300 ms for Go conditions (Fig. 3), additional analysis was performed for NoGo conditions over 350–500 ms.

2.5. Within-subject correlation analysis

To further study how cross-modal distractors affect the CM process, for each Go condition, the correct trials were separated into six batches *within each subject* according to individual RT quantiles at 16.6, 33.3, 50.0, 66.6, and 83.3%. N2 amplitude at Fz/Cz, along with the mean RT, was taken within each batch of trials. Pearson's correlation coefficient between N2 amplitude and mean RT was then computed; sign test was used to assess the robustness of the correlation *across subjects* [18].

3. Results

3.1. Behavioural performance

The pre-planned 2×2 repeated ANOVA between Task (**V**/**AV**) and Congruency (C/I) confirmed our *a priori* hypothesis that the RT congruency effect is larger in **AV** ($M = 75.4$ ms, $SE = 4.4$ ms) than in **V** task ($M = 65.9$ ms, $SE = 4.4$ ms), $F(1, 27) = 9.33$, $p < .01$, $\eta_p^2 = .26$ (see also Section S1, supplementary information, SI).

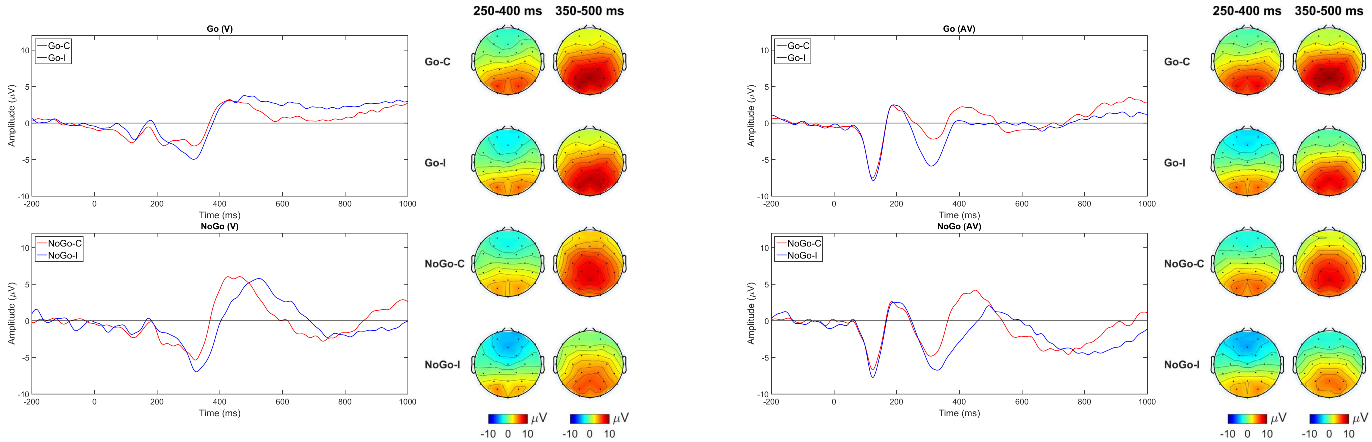

Fig. 2. Grand-averaged ERP at Fz along with the topomaps for Go (top) and NoGo (bottom) conditions in two windows (250–400 ms, and 350–500 ms), shown separately for the V task (left) and AV task (right).

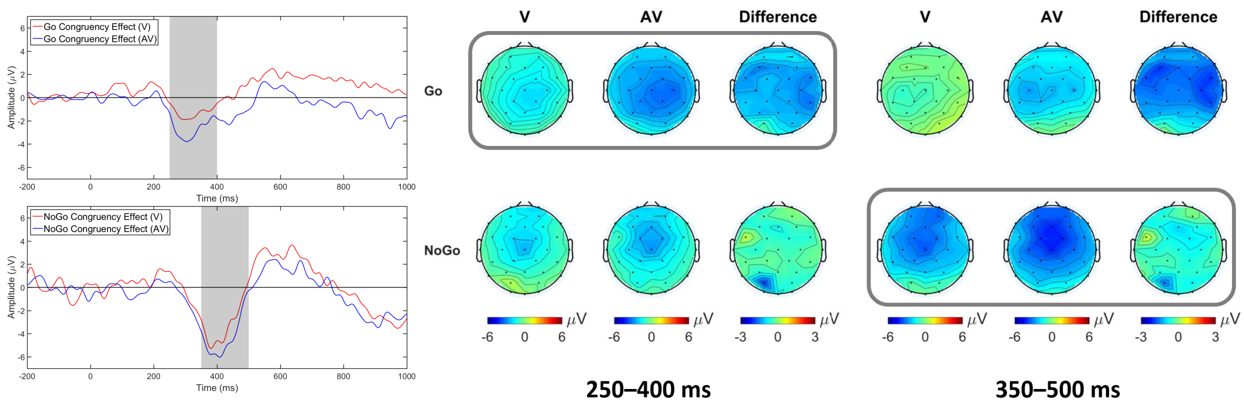

Fig. 3. Differences in N2 amplitude congruency effect across the two tasks (V/AV). Left: Difference wave at Fz showing the N2 amplitude congruency effect (incongruent minus congruent; V and AV in red and blue, respectively) for Go (top) and NoGo (bottom) conditions. The window highlighting the peaks of the difference waves are 250–400 and 350–500 ms, respectively. Right: Topomaps showing the grand-averaged N2 amplitude congruency effect, separately for the two tasks and the two types of responses (Go/NoGo) for both windows.

3.2. ERP findings

Fig. 2 shows the grand-averaged ERP recorded at Fz, for the eight critical conditions. Modulations in amplitude across conditions are evident for the N2 component. However, the difference wave (incongruent minus congruent; Fig. 3, left) consistently revealed the presence of a broad negative underlying component [25], peaking around 300 ms and 400 ms post-stimulus for Go and NoGo conditions, respectively. Importantly, although the congruency effect in NoGo conditions was delayed by about 100 ms, its topography showed a typical frontocentral distribution (Fig. 3, right). Also, the difference wave was numerically more negative in **AV** than **V** task, for both Go and NoGo conditions.

The ANOVA between Task (**V**/**AV**), Congruency (C/I), Site (Fz/Cz) on N2 amplitude for Go conditions showed a significant Task × Congruency interaction, $F(1, 27) = 4.99$, $p < .05$, $\eta_p^2 = .16$, confirming our hypothesis that the congruency effect on N2 amplitude was more negative for **AV** ($M = -2.98$ μV, $SE = 0.47$ μV) than for **V** ($M = -1.63$ μV, $SE = 0.54$ μV). Follow-up analyses revealed that the simple main effect of Congruency was significant for both tasks, **V**: $t(27) = -2.99$, $p < .01$, **AV**, $t(27) = -6.32$, $p < .001$. While the effect of Task was non-significant for both levels of Congruency, N2 amplitude for congruent/incongruent conditions was numerically more positive/negative for **AV** than **V**, C, $t(27) = 1.99$, $p > .05$, I, $t(27) = -0.32$, $p > .74$. This interaction effect was relatively independent on the exact choice for measuring N2 amplitude, being significant even if it was formulated as the peak amplitude or the average amplitude around the peak latency. These analyses, as well as other significant main and interaction effects, are summarized in Section S2, SI. By comparison, the Task × Congruency interaction for NoGo conditions was significant within neither 250–400 ms, $F(1, 27) = 0.44$, $p > .51$, nor 350–500 ms, $F(1, 27) = 1.31$, $p > .26$, although the congruency effect on mean amplitude remained numerically larger for **AV** than **V** task in either window (Section S2, SI). While this is not the main focus of the present study, we have carried out additional analyses to clarify the origin of the NoGo congruency effect at 350–500 ms. These analyses suggested that although the effect was largest at around the P3 peak latency (400 ms), it primarily resulted from a delayed N2 component for NoGo-I relative to the NoGo-C condition (Section S3, SI).

Task	**Site**	**Congruency**					
		Congruent			Incongruent		
		r	N	p	r	N	p
V	Fz	-.42	24	***	-.17	17	n.s.
	Cz	-.53	26	***	-.21	21	*
AV	Fz	-.21	18	n.s.	.14	11	n.s.
	Cz	-.45	24	***	.04	15	n.s.

Table 1. Within-subject N2 amplitude–RT correlation in the two tasks. Each analysis is summarized based on: r, the Pearson's correlation coefficient, N, the number of negative correlations out of a maximum of 28 subjects, and p, of the sign test.

3.3. Within-subject correlation analysis

The within-subject correlation analysis between N2 amplitude and RT quantile [18] revealed interesting differences across task (Table 1 and Section S4, SI). For the **V** task, significant correlation was present for Go-C at Fz, and for both Go-C and Go-I at Cz. For example, the mean within-subject correlation coefficient at Cz was $-.45$ and $-.21$ for Go-C and Go-I, with $r < 0$ for 24/28 and 21/28 subjects, respectively, $p = .001$, and $p < .05$ (sign tests). In contrast, for the **AV** task, the correlation was significant only for Go-C at Cz. No significant correlation could be found for Go-I at either site, suggesting that the relatively tight relationship between N2 amplitude and RT was strongly affected by the presence of to-be-ignored cross-modal distractors, especially for Go-I. To further shed light on these task differences, pairwise t-tests were employed to assess whether the average degree of negative correlation (taken across the two electrodes Fz and Cz) differs across task in general, and for each level of Congruency. Although the correlation was generally less tight for **AV** ($r = -.12$, $SE = .07$) than for **V**($r = -.33$, $SE = .08$), $t(27) = 3.19$, $p < .01$, the difference was clearer for Go-I, $t(27) = 2.83$, $p < .01$, than for Go-C, $t(27) = 1.91$, $p > .06$.

3.4. Supplementary analyses

Because subjects made Go responses with their dominant hand (all subjects were right-handed), they may experience a Simon-like response conflict [26] when target direction was “Left”. Our supplementary analyses ruled out this possibility, as neither the effect of Target Direction nor any interaction effect involving this factor was significant (Section S5, SI). Also, the possibility that the congruency effect was present prior to the N2 window was examined based on the P1/N1 components of the auditory and visual evoked potentials, but the effect was non-significant at all electrode sites examined [23].

4. Discussion

4.1. Cross-modal conflict monitoring

The present study aimed to address the question of whether to-be-ignored auditory distractors introduce additional conflict in a visual conflict task, by examining the behavioural and N2 responses elicited in a visual (**V**) and an audiovisual (**AV**) version of Go/NoGo flanker task. Behaviourally, the congruency effect on RT was larger for **AV** than **V** task, being 75.4 ms and 65.9 ms, respectively. Thus, although subjects were instructed to ignore the auditory distractors and focus only on the visual stimuli in the **AV** task, the auditory distractors did exert a small but significant influence at a behavioural level. More importantly, the ERP data also revealed clear task differences—the congruency effect on N2 amplitude (incongruent minus congruent) in Go conditions was significantly larger (i.e., more negative) for **AV** than **V** task. To our knowledge, our study is the first demonstration that the N2 congruency effect in a visual conflict task is larger in the presence of to-be-ignored cross-modal distractors (auditory words) that are semantically associated with the within-modal distractors (the flankers).

Recently, two behavioural works [14, 15] have examined the effect of to-be-ignored auditory distractors in a visual conflict task. Although both studies adopted Stroop colour–word stimuli as the visual stimuli, only Francis et al. [15] demonstrated significant enhancement in the RT congruency effect when auditory distractors were concurrently presented. Elliott et al. [14] instead observed the reverse pattern, and suggested that the observed reduction might be due to effects of dilution. Given that we observed convergence in our behavioural and neural data that cross-modal distractors could bring about additional conflict, the inconsistency across tasks should be re-examined, e.g., by conducting an ERP study on the AV Stroop task.

4.2. The functional role of N2 component in audiovisual conflict tasks

Some previous works reported a significant within-subject correlation between N2 amplitude and RT in uni-sensory flanker tasks [6, 18]. Yeung et al. [6] provided an elegant explanation of the correlation, in that it implies the functional association between N2 amplitude and response conflict. However, it is known that the ACC is not only sensitive to response conflict but also both within-modal and cross-modal sensory conflict [4, 19, 20]. Extrapolating from ACC to N2 amplitude, if the cross-modal conflict induced by the to-be-ignored auditory distractors in the N2 window is a mixture of cross-modal sensory conflict (e.g., between the target symbol "<" and the auditory distractor "right" in incongruent trials) and response conflict, the N2 amplitude–RT correlation should be weakened. However, if the cross-modal conflict is effective in inducing response conflict, then the same correlation should increase or at least remain the same. To examine this conjecture, within-subject correlation analysis was conducted for each Go condition. In the **V** task, sign tests conducted on the within-subject correlation coefficients confirmed that in agreement with previous works [6, 18], N2 amplitude was negatively correlated with RT for the Go-C and Go-I conditions in at least one of the sites tested (Fz/Cz). However, in the **AV** task, the correlation was significant only for Go-C. Importantly, the correlation was generally less tight in the **AV** than **V** task but especially so in the Go-I condition. These results indicate that, in the **AV** task, N2 amplitude captures an additional significant source of influence, but this change in N2 amplitude is unlikely to index additional response conflict. In other words, due to the presence of the to-be-ignored auditory distractors, the N2 amplitude reflects the cross-modal sensory conflict between the visual target and the auditory word, in addition to the response conflict. While the cross-modal conflict was detected by the CM process, due to the task instructions to respond only to visual stimuli, only part of this influence was effective in inducing response conflict and triggering the enhanced RT congruency effect, thereby weakening the N2 amplitude–RT correlation. This interpretation aligns well with the multi-level and multi-sensory framework regarding the CM function of ACC [4].

4.3. Limitations and future work

First, the additional influence of to-be-ignored auditory distractors on N2 amplitude was only significant for Go conditions. In contrast, although the NoGo congruency effect was exhibited as an N2 latency effect and an amplitude effect at about 400 ms, neither effect was modulated across the two tasks (Section S3, SI). This apparent lack of sensitivity toward auditory distractors in NoGo conditions is unlikely due to the smaller number of trials per condition (48 vs. 96), given that the standard errors of the mean amplitude were similar across all Go (0.97–1.07 μV) and NoGo (1.00–1.06 μV) conditions. It therefore appears that cross-modal distractors have relatively less influence on response inhibition (NoGo) than execution (Go), although further evidence should be sought to confirm this conclusion from the present exploratory analysis. Second, we acknowledged that cross-modal distractors may induce congruency effects at lower levels of processing, which are reflected by earlier ERP components, e.g., P1, N1 and P2. Although such effects were absent in the present study [23], congruency effects on P2 amplitude in uni-sensory tasks have been reported [e.g., 27]. These sensory effects, if present, would likely be fed forward to the CM network, producing the effects that we observed here with the N2 component. Future work is required to examine this complex interaction between the CM process and the lower-level sensory processes in an AV scenario. Third, the present work provided some evidence that within-subject N2 amplitude–RT correlation was weakened in an AV task, when the to-be-ignored auditory distractors were semantically associated with the flankers. Should these auditory distractors be semantically associated with the target arrows instead, it is likely that they would no longer induce cross-modal conflicts. Under this situation, the correlation might be restored to a level comparable to that of the visual flanker task. Future work could test this hypothesis by manipulating the probability that the auditory distractors are congruent with the target.

5. Conclusion

In this work, to-be-ignored auditory distractors were found to introduce additional influence on the conflict monitoring process in the audiovisual vs. visual flanker task, as evidenced by a larger congruency effect on N2 amplitude. On the basis of correlation analysis between N2 amplitude and RT, we concluded that while N2 amplitude represents primarily response conflict in the visual flanker task (in agreement with previous works), only part of the cross-modal conflict in the audiovisual task could effectively induce response conflict. This interpretation aligns well with this multi-level framework regarding the conflict monitoring function of ACC.

Appendix: Supplementary information

Supplementary information is included.

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