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Title page

Electrophysiological correlates of crossmodal visual distractor congruency effects: evidence for response conflict

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Abstract

To investigate the basis of crossmodal visual distractor congruency effects we recorded event-related brain potentials (ERP) while participants performed a tactile location discrimination task. Participants made speeded tactile location discrimination responses to tactile targets presented to the index fingers or thumbs while ignoring simultaneously presented task-irrelevant visual distractor stimuli at either the same (congruent) or a different (incongruent) location. Behavioural results were in line with previous studies showing slowed response times and increased error rates on incongruent compared to congruent visual distractor trials. To clarify the effect of visual distractors on tactile processing, concurrently recorded ERPs were analysed for post-stimulus, pre-response and post-response modulations. An enhanced negativity was found in the time range of the N2 component on incongruent compared to congruent visual distractor trials prior to correct responses. In addition, post-response ERPs showed the presence of ERN components on incorrect response trials and enhanced negativity for congruent-incorrect compared to incongruent-incorrect trials. This pattern of ERP results has previously been related to response conflict (Yeung, Cohen, & Botvinick, 2004). Importantly, no modulation of early somatosensory ERPs was present prior to the N2 time range, which may have suggested the contribution of other perceptual or post-perceptual processes to crossmodal congruency effects. Taken together, our results suggest that crossmodal visual distractor effects are largely due to response conflict.

Introduction.

Investigations into the effects of events in one modality upon processing of events in another modality and the integration of information across sensory modalities have recently gained increasing interest (see chapters in Calvert, Spence, & Stein, 2004 and in Spence and Driver, 2004). Moreover, investigations into the interactions between visual and tactile events have revealed spatial constraints of peripersonal and extrapersonal space perception (see Maravita, Spence, & Driver, 2003 for review). While tactile events define our proximal boundaries visual events can occur close to the body surface or at some distance; and further, depending on the perceived distance of visual stimuli from tactile events visual task-irrelevant stimuli may influence tactile discrimination judgements (see Spence, Pavani, Maravita, & Holmes, 2004b for review).

Specifically one paradigm, the visual-tactile cross-modal distractor congruency task has been used to investigate the multisensory construction of space (e.g. Maravita et al., 2003). In this paradigm participants typically hold two cubes, one in either hand. One tactile stimulator and one light-emitting diode (LED) are placed in the upper and lower surface of each cube directly under or close to the index finger and thumb of each hand. On each trial, one tactile target and one visual distractor are presented simultaneously at any one of the four possible locations. The participants' task is to identify the location of the tactile target (top or bottom) while ignoring visual distractors. Visual distractors and tactile targets are presented either from the same location or different locations. Participants are typically slower and less accurate at discriminating the location of vibrotactile targets when simultaneously presented with a visual distractor from a different/incongruent location (i.e., tactile targets are presented at top locations and visual distractors at bottom locations, or vice versa) compared to when both tactile target and visual distractor are presented from the same/congruent location (i.e., either both from the same top or both from the same bottom location). This difference in performance between incongruent and congruent trials is taken as an indication of visual distractor influence on tactile target discriminations.

Several explanations have been put forward to account for the influence of task irrelevant visual events on tactile discriminations as seen in the crossmodal congruency task. These explanations suggest

either perceptual interactions between vision and touch or higher cognitive processes as the bases of crossmodal congruency effects. To investigate a perceptual basis of crossmodal congruency effects Spence, Pavani and Driver (2004a, Appendix) asked participants to perform as accurately as possible in a crossmodal congruency task. Under these un-speeded conditions participants committed only a very low number of errors. These results suggest that the contribution of early perceptual interactions between vision and touch to crossmodal congruency effects are, if anything, minimal as perceptual misplacement of tactile targets towards the location of visual distractors should be independent of time pressure (Spence et al., 2004a).

In addition to a perceptual explanation, two further explanations have been put forward to account for crossmodal visual distractor congruency effects. One is based on the assumption that visual distractors act as spatial attentional cues shifting participants' attention to the visual distractor location, thus resulting in slower response times (RT) and increased errors when the tactile targets and visual distractors are presented from incongruent locations. Likewise, several studies have shown crossmodal congruency effects also when visual distractors are presented before vibrotactile targets (Kennett, Spence, & Driver, 2002; Shore, Barnes, & Spence, 2006; Spence et al., 2004a) suggesting that under these timing conditions visual distractors may act as spatial attentional pre-cues. According to the attentional cue account of crossmodal congruency effects tactile discrimination is facilitated when visual distractors and tactile targets are presented from the same location compared to when these are presented from different hands/sides. However, this account fails to explain maximal interference effects of visual distractors when presented at the same hand/side as tactile targets (but a different location). According to the spatial attentional cue explanation, visual distractors close to the target location (e.g. at the same hand) should facilitate responses. However, stronger interference of distractors close to the target location is typically found.

The other post-perceptual explanation is based on the assumption that crossmodal congruency effects reflect response conflict (Spence et al., 2004a; see also Shore, & Simic, 2005; Shore et al. 2006). This account explains the influence of incongruent visual distractors on tactile discriminations by means

of inappropriate response priming of visual incongruent distractors while congruent distractors facilitate responses by priming the appropriate response. In contrast to the attentional explanation, response conflict can account for the behavioural interference effect of visual distractors presented close to tactile targets but at a location associated with a different response.

According to the response conflict account of the crossmodal congruency task both visual distractor and tactile targets activate separate response representations that are in conflict when distractor and target are presented at locations associated with different responses (e.g. target at top and distractor at bottom locations). During performance of a task, cognitive control processes are thought to monitor and regulate ongoing processes in a goal-directed manner and this includes detection of conflict during information processing, that may arise from activation of different response representations, and the detection and correction of error responses. Event-related brain potential (ERP) studies investigating the neural response of performance monitoring have typically investigated the neural response following error responses (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Gross, Coles, Meyer, & Donchin, 1993), and recently, neural processes prior to response execution have also been linked to monitoring processes (Nieuwenhuis, Yeung, van den Wildenberg, Ridderinkof, 2003; Yeung, Cohen, & Botvinick, 2004). According to the conflict theory (Botvinick, Braver, Barch, Carter, & Cohen, 2001) the performance monitoring system provides a continuous evaluation of the degree of conflict that is generated by the activation of competing response units. Furthermore, Yeung et al. (2004) suggested that both neural responses prior to and post response execution reflect the amount of conflict present, that is, conflict associated with correct responses is present prior to and conflict associated with erroneous responses is present after response execution.

Following Yeung et al.'s (2004) account of conflict monitoring, we investigated whether electrophysiological correlates of response conflict are present in the crossmodal visual distractor congruency task. Therefore, prior to the execution of correct responses incongruent visual distractors should induce stronger response conflict than congruent visual distractors due to the ambiguity of incongruent stimuli that leads to increased conflict to select the appropriate response. Likewise,

electrophysiological studies of pre-response conflict have reported that the N2 component, which is present around 250 ms after stimulus onset in stimulus-locked and around 150 ms prior to a response in response-locked waveforms, shows increased negativity on incongruent compared to congruent trials (Kopp, Rist, & Mattler 1996; Liotti, Woldorff, Perez, & Mayberg, 2000, Nieuwenhuis et al., 2003). Similarly, in the crossmodal visual distractor congruency task conflict should be reflected in enhanced negativity of N2 components of event-related potentials (ERP) when visual distractors and tactile targets are incongruent compared to when these are presented from congruent locations.

In addition, after the execution of responses conflict should be stronger for erroneous responses on congruent than incongruent trials. This assumption is based on the suggestions that we constantly monitor our actions and compare these to internal representation of correct responses. In the case of erroneous responses, a mismatch is detected which is reflected in the 'error related negativity' (ERN) (Gehring et al., 1993; see also Falkenstein et al., 1991) present shortly after execution of erroneous responses. Originally, this component was thought to reflect the detection of error commission (Falkenstein et al., 1991; Gehring et al., 1993) however, recently it has been suggested to reflect the amount of conflict present immediately after response execution and to be closely related to error-correcting activity (Botvinick et al., 2004; Yeung et al. 2004). Therefore, after an erroneous response conflict between the representation of the correct response and the actual incorrect response should be present, and furthermore, this conflict should be stronger for erroneous responses on congruent trials than on incongruent trials. Response conflict should therefore be the strongest immediately following an incorrect response when visual distractors are presented from the same congruent location as tactile targets. This is due to conflict between the equal activations of response representation by visual distractors and tactile targets that are both in conflict with the actual incorrect response. In contrast, on incongruent visual distractor trials only tactile targets activate response representations different from the actual incorrect response thus leading to less response conflict than on congruent visual distractor trials.

To investigate the hypothesis that crossmodal visual distractor congruency effects reflect response conflict, we measured participants behavioural performance in tactile location discriminations ("upper" at

the index finger vs. "lower" at the thumb) while ignoring visual distractors presented from the same or from a different location on the same hand (e.g. both at the index finger or one at the index finger the other at the thumb)[1]. Concurrently recorded ERPs were analysed in the time range of the N2 and ERN components. According to the conflict monitoring theory we expect to find correlates of response conflict activity on correct trials prior to (N2) and on error trials following (ERN) response execution. In addition, we also analyzed early somatosensory components to investigate the hypothesis that perceptual or attentional orienting processes were the bases of the crossmodal visual distractor congruency effect. Attentional modulations have repeatedly been reported to enhance the N140 component (e.g. Desmedt, & Robertson, 1977; Eimer, & Forster, 2003; Forster, & Eimer, 2004, 2005; García-Larrea, Lukaszewicz, & Mauguière, 1995; Michie, Bearpark, Crawford, & Glue, 1987) while a study by Schürmann, Kolev, Menzel, & Yordanova (2002) found that perceptual interaction between vision and touch result in modulations of early somatosensory components already starting in the time range of the P100 component. Therefore, with respect to stimulus-locked ERP components, we analysed in addition to the longer-latency N2 component which has been related to response conflict, early somatosensory components present around 100 ms (P100) and 140 ms (N140) after stimulus onset, to investigate early perceptual and attentional effects of visual distractors on tactile processing.

Method.

Participants.

Twelve volunteers (5 males and 7 females) with a mean age of 28 years (ranging from 21 to 37 years), participated in the experiment. All participants were naive regarding the purpose of the experiment. All were right-handed by self-report, had normal or corrected-to-normal vision and all reported having normal touch. Participants gave their written informed consent prior to their participation.

Apparatus, Stimuli and Procedure.

Participants sat at a table in a dimly lit room, with their forearms placed comfortably on the tabletop in front of them, and holding a wooden cube (7cm high x 3cm wide x 5cm deep) between the thumb and index finger of each hand. Between the cubes a 20 cm wide piece of cardboard was placed at a 45º angle on the table surface. A black fixation cross was drawn on the centre of the cardboard and the midline of the cubes was aligned with the horizontal line of the fixation cross. Participants were asked to tilt the cubes so that the side facing the participant was parallel to the cardboard surface. Each cube had two solenoids embedded; one in the lower and one in the upper surface placed directly under the thumb and index finger of each hand. Tactile stimuli were presented using 12-V solenoids, driving a metal rod with a conical tip to the finger pad, making contact with the fingers whenever a current was passed through the solenoid. Tactile target stimuli consisted of one rod contacting a finger for 80 ms; this gave rise to a suprathreshold touch sensation. Four red LEDs (5 mm in diameter) were also mounted on the cubes, two on each, to provide the visual distractor stimuli; one was placed next to each of the four tactile stimulators. Visual distractor stimuli consisted of the illumination of one LED for 80 ms. On each trial, one tactile target and one visual distractor stimulus were presented simultaneously from the same cube (both from either the left or the right cube) at either the same location (both at either the upper or lower cube side) or at opposite locations (one at the upper the other at the lower cube side). Participants responded by pressing one of the two foot pedals located under their right and left foot. White noise was presented from a loudspeaker directly in front of the participants to mask any sounds made by the operation of the solenoids.

Fifteen experimental blocks with 64 trials per block were run. A block of 64 practice trials was given before the start of the experiment. The practice trials were excluded from the final analysis. On 32 trials of each block, one target and one distractor were presented from the same location (congruent trials), and on the remaining 32 trials, target and distractor were presented from opposite locations (incongruent trials). Congruent and incongruent trials were presented with equal probability from the left and right cube. Participants were instructed to make speeded location discriminations to tactile targets by pressing one of two foot pedals. Half of the participants pressed the right foot pedal when the target

appeared at upper locations and the left foot paddle to indicate lower locations. For the remaining participants this association between target location and response foot was reversed. If no response was made within 700 ms of target onset, an acoustic feedback (1000 Hz) was presented for 500 ms before the start of the next trial. The inter-trial interval was 620 ms.

Data acquisition and analysis

EEG was recorded with Ag-AgCl electrodes and linked-earlobe reference[2] from Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T7, T8, P7, P8, Fz, FCz, Cz, Pz, FC1, FC2, CP1, CP2, FC5, FC6, CP5 and CP6 (according to the 10-20 system). Horizontal EOG (HEOG) was recorded bipolarly from electrodes positioned on the outer canthii of both eyes. A Brain-Amps amplifier system and Brain Vision Recorder and Analyzer 1.05 software (Brain Products, GmbH) were used for recording and offline analysis of the EEG data. Impedance was kept below 2 KΩ for reference and ground electrodes and below 5 KΩ for all other electrodes, amplifier band-pass was 0.01 to 100 Hz, and digitization rate was 500Hz. EEG and HEOG were epoched in separate off-line analyses. To investigate stimulus-locked ERPs, epochs we extracted for a period starting 200 ms prior until 800 ms after to the onset of the visual and tactile stimuli, and to investigate response-locked ERPs, epochs were extracted for a period from 800 ms prior until 100 ms after a response ('pre-response ERPs'), and for a period from 200 ms prior until 600 ms after the onset of the participants' response ('post-response ERPs'). Trials with horizontal eye movements, eye blinks or any other artifact, and trials with RTs below 100 ms and above 1000 ms were excluded separately for each epoch type.

Stimulus-locked ERPs were averaged relative to a 200 ms pre-stimulus baseline for target-distractor congruency and response accuracy resulting in four averages (condition [mean number of trials; range]): congruent-correct trials [407; 234-456]; congruent-incorrect trials [37; 11-163]; incongruent-correct trials [339; 94-429]; and incongruent-incorrect trials [86; 38-160]. Post-response ERPs were also averaged relative to a 200 ms pre-response baseline based on target-distractor congruency and response accuracy resulting in four different averages: congruent-correct trials [313; 39-451]; congruent-incorrect

trials [30; 1-149]; incongruent-correct trials [249; 24-420]; and incongruent-incorrect trials [54; 5-138]. All averages were then filtered with a low-pass digital filter (zero-phase shift type) of 30Hz.

To further explore N2 effects, difference waveforms of stimulus-locked ERPs were calculated by subtracting ERP waveforms elicited on congruent-correct trials from ERP waveforms elicited on incongruent-correct trials. In addition, pre-response ERPs elicited on incongruent-correct [285; 94-424], congruent-correct [353; 195-461] and error trials [106; 12-168] trials were averaged relative to a baseline taken from 800 to 700 ms prior to the response and were filtered with a low-pass digital filter of 30 Hz. In addition, a high-pass filter with a low cutoff of 2 Hz was applied to both difference waveforms and pre-response ERPs (further exploring N2 effects), to remove the contribution of slow parietal positivities that may mask the frontocentral negativities of interest (see, for example, Yeung et al. 2004).

ERP mean amplitudes were computed for each participant for the averages of response-locked ERPs for the time window of the N2 component (-180 to -80 ms prior to the onset of participants' responses in pre-response ERPs) and the ERN component (20-120 ms following the onset of participants' responses in post-response ERPs), and for the averages of stimulus-locked ERPs for the time window of the somatosensory P100 (80 – 128 ms), N140 (130 – 174 ms) and the N2 component (210-310 ms; all time windows following the onset of simultaneous presented tactile and visual stimuli).

Statistical analyses were conducted for midline electrode sites (Fz, FCz, Cz and Pz) to investigate the N2 and ERN components, and for lateral electrode sites (F3, F4, FC5, FC6, C3, C4, CP5, CP6, P3, P4) over the left and right hemisphere close to and over somatosensory cortex to investigate modulations of the early P100 and N140 somatosensory components. Separate ANOVAs were conducted for mean amplitude values in the time range of the P100 (80 – 128 ms post-stimulus onset), N140 (130 – 174 ms post-stimulus onset), N2 (210 – 310 ms post-stimulus, and -180 – -80 ms pre-response onset), and ERN (20 – 120 ms post-response onset) components with factors visual distractor location (congruent versus incongruent), response type (correct versus incorrect), and electrode (Fz, Cz, FCz and Pz) for midline electrode site analyses, or electrode (F3/4, FC5/6, C3/C4, CP5/CP6, P3/P4) and hemisphere (ipsilateral versus contralateral to the side of stimulation) for lateral electrode site analyses. Mean amplitude ERP

values and behavioural data were analysed using SPSS (version 11.1) General Linear Model (GLM) software with the Greenhouse-Geisser correction for non-sphericity applied where appropriate.

Results

INSERT TABLE 1 ABOUT HERE

Behavioural Results

Trials on which participants made a premature response (RT < 100 ms) or failed to respond within 1000 ms were removed from both RT and accuracy analyses. This resulted in the removal of on average of 3.45% of trials across all participants. Accuracy and mean RTs of correct responses were analyzed separately using a repeated measures analysis of variance (ANOVA) with factors tactile target location (Up versus Down) and visual distractor congruency (congruent versus incongruent). Table 1 shows average RTs and error rates separately for trials when visual distractors and tactile targets were congruent and incongruent. Participants responded on average 68 ms faster and committed fewer mistakes when visual distractors were congruent with tactile stimuli. Statistical analysis showed a main effect of visual distractor congruency for RTs [469 ms compared to 537 ms; $F(1, 11) = 75.77$, $p < .0001$] and error rates [24 % compared to 9 %; $F(1,11) = 7.76$, $p = .02$].

INSERT FIGURE 1 and 2 ABOUT HERE

ERP Results

To investigate modulations of early somatosensory components (P100 and N140) and components associated with response conflict (N2 and ERN), post-stimulus (P100, N140 and N2), pre-response (N2) and post-response (ERN) ERP waveforms were analysed.

Post-Stimulus ERPs. Figure 1 shows stimulus-locked ERPs elicited by congruent (solid lines) and incongruent (dashed lines) visual distractor and tactile target stimuli prior to the execution of correct responses. Starting around the onset of the N2 component at about 200 ms after stimuli onset an enhanced negativity on incongruent compared to congruent trials is present and no modulations are present prior to this. Statistical analysis showed no significant main effect of or interaction involving the factors visual distractor location or response type in the time range of the P100 or N140 components. For the following analysis window of the N2 component a main effect of visual distractor location [$F(1, 11) = 13.11$, $p < .01$] and a visual distractor location by response type interaction [$F(1, 11) = 10.34$, $p < .01$] was present. Follow-up analysis separate for correct and incorrect response trials showed a significant visual distractor location effect only for correct response trials [$F(1, 11) = 22.77$, $p < .01$ for correct; and $F(1, 11) < 1$, n.s. for incorrect response trials] confirming enhanced N2 amplitudes when visual distractors were incongruent with tactile target locations prior to correct responses.

To further explore the enhancement of ERPs on incongruent-correct compared to congruent-correct trials, difference waveforms were calculated by subtracting ERPs on congruent-correct from incongruent-correct trials. Figure 2 shows the topographic distribution of the enhancement of incongruent-correct trials that was centred over frontocentral electrode sites for the time range of the N2 component (210 – 310 ms after stimulus onset; left panel). In contrast, for the subsequent time window (330 – 430 ms after stimulus onset; right panel) the difference in ERP waveforms between incongruent and congruent correct trials was more pronounced over posterior electrode sites.

Pre-Response ERPs. Figure 2 shows the relative timing of the N2 and the ERN in response-locked ERPs. The upper panel shows ERP waveforms elicited on incongruent-correct (solid line), congruent-correct (dashed line) and on incorrect (dashed-dotted line) response trials at electrode FCz. The N2 is clearly visible on correct response trials prior to response onset, while the ERN is present following

response onset. ERP amplitudes were more negative on incongruent than on congruent correct trials starting around 200 ms prior to the response. Statistical analysis of correct response trials with the factors visual distractor location and electrode showed a main effect of visual distractor location [$F(1,11) = 13.00$; $p < .01$] confirming the presence of an enhanced negativity on incongruent correct trials also in response-locked ERPs. To further explore the topographic distribution of the N2 modulation present in response-locked ERPs, difference waveforms were calculated by subtracting ERPs on congruent-correct from incongruent-correct trials. The lower panel of Figure 3 shows a frontocentral distribution of the N2 modulation (left side), similar to the topographic distribution seen after response execution (ERN; right side).

Post-Response ERPs. Figure 3 shows response-locked ERP waveforms on congruent (dashed line) and incongruent (dashed-dotted line) incorrect response trials and on correct response trials averaged across incongruent and congruent visual distractor trials (solid line). ERP amplitudes are more negative on incorrect compared to correct response trials with ERN components clearly present on incorrect response trials immediately following response execution. Furthermore, ERN amplitudes are more negative on congruent than on incongruent incorrect response trials. These observations were substantiated by statistical analysis that showed a main effect of response type [$F(1, 11) = 17.18$, $p < .01$] confirming the presence of ERN components with more negative ERP amplitudes on incorrect compared to correct response trials, and a main effect of visual distractor location [$F(1, 11) = 9.02$, $p < .02$] reflecting larger ERP amplitudes when visual distractors were congruent compared to when these were incongruent with tactile targets. In addition, a main effect of electrode [$F(3, 33) = 15.29$, $p < .001$] and a significant electrode by response type interaction [$F(3, 33) = 6.20$, $p < .01$] were present. Follow-up analyses separate for each electrode showed significantly more negative ERP amplitudes values on incorrect compared to correct response trials at all electrodes [all $t(1/11) > 3.18$; $p < .01$]. To further investigate the effect of visual distractor location two one-way ANOVAs were performed separately for correct and incorrect response trials with factors visual distractor location and electrode. This analysis showed a main effect of visual distractor location on incorrect response trials only [$F(1,11) = 8.95$, $p < .02$; and $F(1,11)$

= 4.17, n.s. on correct response trials] confirming that visual distractor congruency effects on ERN components were only elicited following incorrect responses.

Discussion

In the present study, ERP markers of response conflict were evaluated in a crossmodal visual distractor congruency task. Participants performed a tactile location (up or down) discrimination task while ignoring visual distractors delivered at either the same location as tactile targets (congruent) or at opposite locations (incongruent). In line with previous behavioural findings (Shore et al., 2006; see Spence et al., 2004a for review) participants were faster and more accurate when tactile targets and visual distractors were congruent than when these were incongruent suggesting that the location of the task irrelevant distractor lights has a profound effect on location judgments of tactile target stimuli. Furthermore, electrophysiological correlates of response conflict were present before and after response execution suggesting task-irrelevant visual stimuli induced response conflict when presented from locations incongruent to those of tactile targets.

We found that electrophysiological correlates of stimulus processing showed enhanced negativity, for incongruent compared to congruent visual distractor trials, that was present prior to correct response execution starting in the time range of the N2 component. Likewise, previous studies, investigating ERP correlates of response conflict, have reported modulation of the N2 component on correct response trials when response incongruent distractors were present (Davies, Segalowitz, Dywan, & Pailing, 2001; Nieuwenhuis et al., 2003; Yeung et al., 2004). We found an enhanced negativity for incongruent compared to congruent correct trials to be present in the time range of the N2 in stimulus-locked waveforms. The difference in stimulus-locked ERP waveforms between incongruent and congruent correct trials was largest over frontocentral electrode sites for the time range of the N2, while this difference showed a posterior distribution for later latencies. An enhanced negativity for incongruent compared to congruent correct trials was also present prior to response execution in response-locked ERPs, and the difference of these waveforms revealed again a frontocentral distribution of the N2

modulation. Therefore, our results suggest, that prior to correct tactile location discriminations simultaneously presented task-irrelevant visual distractors induce response conflict when presented from a location associated with a different response. In contrast, after response execution no reliable difference between incongruent-correct and congruent-correct trials was present suggesting the presence of pre-response conflict on correct response trials that diminishes after response execution (see Yeung et al., 2004).

In addition to the presence of pre-response conflict as reflected in modulations of the N2 component, we also report the presence of ERN components immediately following incorrect response execution. The presence of ERN components only after erroneous responses is in line with previous studies suggesting that this component is related to on-line monitoring of responses reflecting conflict detection between the representation of the correct response and the actual incorrect response (Botvinick et al., 2001; Yeung et al., 2004). Furthermore, we found ERNs to be larger on congruent compared to incongruent trials in line with the prediction that post-response conflict after an incorrect response is larger on trials when both tactile target and visual distractor are presented from congruent than from incongruent locations. These findings are consistent with results of a simulation study of the connectionist model of conflict monitoring (Yeung et al., 2004) suggesting stronger response conflict after incorrect responses resulting from greater activation of correct response representations when both distractor and target are congruent than when these are incongruent.

Both the N2 and ERN components have been suggested to reflect conflict monitoring processes. In line with previous studies we also found that both components show similar topographic distributions (Figure 3), and it has been suggested that both share a neural source located in the Anterior Cingulate Cortex (e.g. Dehaene, Posner, & Tucker, 1994; Holroyd, Dien, & Coles, 1998; Nieuwenhuis et al., 2003; van Veen, & Carter, 2002). Furthermore, enhanced N2 components by stimuli associated with incongruent responses prior to correct responses and enhanced ERN components following erroneous responses have been observed in situations characterized by high response conflict like the Flanker (Kopp et al., 1996; Yeung et al., 2004), Stroop (Liotti et al., 2000; Gehring et al., 1993) and go-nogo tasks

(Nieuwenhuis et al., 2003). Likewise, we observed a similar pattern of modulations of the N2 and ERN components in the crossmodal congruency task suggesting that task-irrelevant visual distractors induce response conflict when presented close to tactile target locations but at a location associated with a different response.

Attentional modulations of tactile processing are typically seen in enhancement of the somatosensory N140 component followed by a sustained negativity for later latencies (e.g. Desmedt, & Robertson, 1977; Eimer, & Forster, 2003; Eimer, Forster, Fieger, & Harbich, 2004; Forster, Eardley, & Eimer, 2007; Forster, & Eimer, 2004, 2005; García-Larrea et al., 1995; Michie et al., 1987; Van Velzen, Forster, & Eimer, 2002). If in the crossmodal congruency task visual distractors were acting as attention directing cues, the strongest cueing effects should be seen when visual distractors and tactile targets were presented at the same location. This would be reflected in an enhanced negativity for stimuli presented at congruent compared to incongruent locations. However, no modulations of early somatosensory ERPs dependent on visual distractor congruency were present in the time range of the N140 component. Moreover, an enhanced negativity was present at later latencies but this reflected enhanced processing when visual distractors were presented at locations incongruent to tactile targets. Taken together, our results do not support the attentional cue account of visual distractor congruency effects, rather our electrophysiological results are in line with the response conflict account.

In the present study visual distractors were only presented from locations on the same hand as tactile targets since under these conditions visual distractor effects are maximal. Therefore, in the present study one condition, that is commonly included in a visual-tactile cross-modal distractor congruency task, was excluded. Including such a condition could have made it easier to observe crossmodal attentional facilitation effects. In this condition visual distractor and tactile target are presented at opposite sides (e.g. tactile target at the left hand and visual distractor at the right hand). Following the attentional explanation of cross-modal congruency effects, visual distractors may act as exogenous attentional cues that facilitate tactile target processing when presented from the same location. Therefore, by comparing ERPs elicited on trials when visual distractors are presented from the same location as tactile targets compared to ERPs

elicited on trials when tactile target and visual distractor are presented from opposite sides, cross-modal exogenous attentional effects on early somatosenory processing could be revealed.

The conflict monitoring theory (Botvinick et al., 2001 and Yeung et al., 2004) states that conflict occurs when two or more incompatible response representations are activated. In the present study, participants performed speeded tactile discriminations in a crossmodal visual distractor congruency task where visual distractors were presented from either congruent or incongruent locations on the same hand. Previous behavioural studies have typically included a condition were incongruent visual distractors are presented from an incongruent location on the hand opposite to the tactile target location (e.g. visual distractor bottom left hand and tactile target top right hand). Under this condition visual distractor effects on tactile location discrimination is attenuated compared to when visual distractors are presented from an incongruent location on the same hand as the tactile target (e.g. Spence et al., 2004a; 2004b). Therefore, especially visual distractors close to or perceived as close to the tactile target site but at a response incongruent location interfere adversely with tactile target location discriminations (see Spence et al., 2004a for review). Under both conditions (same versus different hand) visual distractors are presented from an incongruent location and according to the response conflict account should induce similar amounts of conflict. Therefore, the difference in visual distractor effects was found to be dependent on the proximity of visual distractor and tactile target locations. This may suggest that additional perceptual interaction between visual distractors and tactile targets take place when both stimuli are presented from the same hand. However, while visuo-tactile interactions have been reported to be reflected in modulations already present in the time range of the early somatosensory P100 component (Schürmann et al., 2002) for spatially congruent compared to incongruent visuo-tactile stimuli we only found modulation of longer latency components[3]. Longer-latency modulations have been related to post-perceptual processes reflecting in depth stimulus processing of task-relevant stimuli (Michie, 1984).

In sum, in the present study behavioural and electrophysiological correlates of post-stimulus and post-response processing were evaluated in a crossmodal congruency task. Participants RTs were slower and error rates increased when task-irrelevant visual distractor were presented from incongruent locations

to tactile targets. Furthermore, concurrently recorded ERPs showed enhanced negativity of the N2 component for incongruent compared to congruent correct response trials; in addition, post-response ERNs were enhanced on congruent error trials. This pattern of ERP results has previously been related to the presence of pre- and post-response conflict (Yeung et al., 2004). Taken together, our results suggest that crossmodal visual distractor congruency effects are largely due to response conflict.

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Figure and Table Captions

Figure 1. Grand-averaged ERPs in response to congruent (solid lines) and incongruent (dashed lines) visual distractor and tactile target stimuli in the 600 ms following stimuli onset prior to correct responses. ERPs are shown at electrode sites over the hemisphere contralateral and ipsilateral to the stimulated hand and at midline electrodes.

Figure 2. Scalp voltage maps, for the time range of the N2 effect (210 – 310 ms post-stimulus; left side) and subsequent time range (330 – 430 ms post-stimulus; right side), of the difference of stimulus-locked ERP waveforms elicited on congruent-correct trials subtracted from ERP waveforms elicited on incongruent-correct trials.

Figure 3. *Upper panel*: Grand-averaged ERPs elicited on correct responses trials separate for congruent (solid line) and incongruent (dashed line) visual distractor trials, and on erroneous responses trials (dotted-dashed line) in the 800ms prior to and the 200 ms following a response at electrode FCz. *Lower panel*: Scalp voltage maps for the time point of the N2 component (-126 ms pre-response; left side) and the ERN (76 ms post-response; right side). The left map shows the difference of ERP waveforms elicited on congruent-correct trials subtracted from ERP waveforms elicited on incongruent-correct trials; the right map shows ERPs elicited on erroneous response trials averaged across congruent and incongruent visual distractor trials.

Figure 4. Grand-averaged ERPs elicited after correct responses (solid line) and erroneous responses separate for congruent (dashed line) and incongruent (dashed-dotted line) visual distractor trials in the 600ms following response onset at electrode FCz. ERPs on correct response trials are averaged across congruent-correct and incongruent-correct trials.

Table 1. Mean Reaction Times (M RTs in milliseconds), their standard deviation (S.D. in milliseconds) and percentages of errors (%E) for tactile target location discriminations shown separately for congruent and incongruent visual distractor trials.

Footnotes

[1] Typically visual distractors are presented at either the same hand as tactile targets or the other hand. In the present study visual distractors were only presented from locations on the same hand as tactile targets since under these conditions visual distractor effects are maximal.

[2] Early somatosensory modulations (i.e. in the time range of the P100 and N140 components) have been reported in numerous previous studies that have also employed linked earlobe references (e.g. Eimer, & Forster, 2003; Eimer et al., 2004; Forster et al., 2007; Forster, & Eimer, 2004, 2005; Michie, 1984; Michie et al., 1987; Van Velzen et al., 2002); although, also single earlobes (Desmedt, & Robertson, 1977) and the nose (García-Larrea et al., 1995) have been used as reference sites. Thus, the absence of any early somatosensory modulations in the present study is most likely not due to the use of linked earlobe references.

[3]The absence of any attentional or perceptual effects on somatosensory processing is most likely not linked to data acquisition or analysis procedures. The authors have previously shown attentional (e.g. Forster et al. 2007; Forster, & Eimer, 2005) and perceptual (e.g. Forster, & Eimer, 2005) effects on early somatosensory processing when using similar experimental set-ups, EEG recording and analysis procedures, and testing the same number of participants.

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Visual distractor location	RTs		
	M	S.D.	% E
congruent	469	15.73	9%
incongruent	537	16.65	24%

Table 1

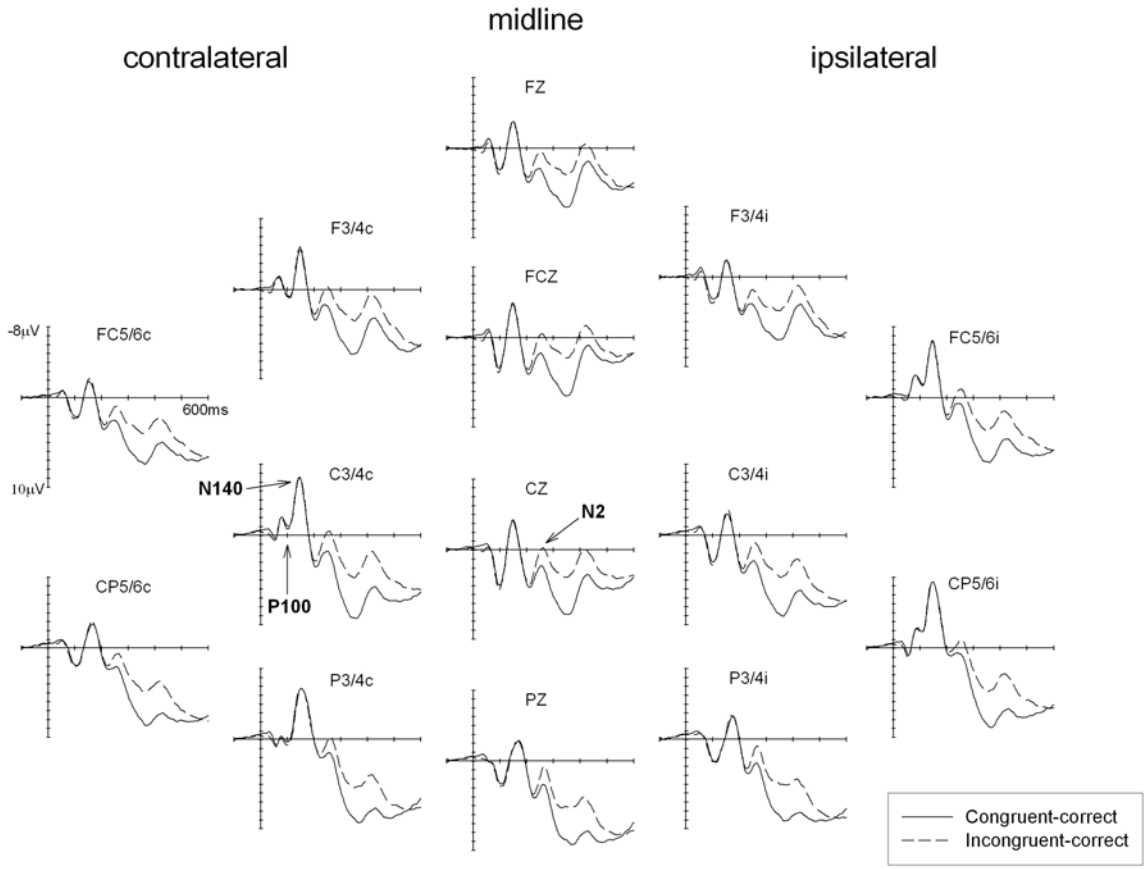
midline
contralateral
ipsilateral
FZ
F3/4c
F3/4i
FCZ
-8μV
FC5/6c
FC5/6i
600ms
10μV
N140
C3/4c
CZ
N2
C3/4i
CP5/6c
P100
CP5/6i
P3/4c
PZ
P3/4i
Congruent-correct
Incongruent-correct

Figure 1

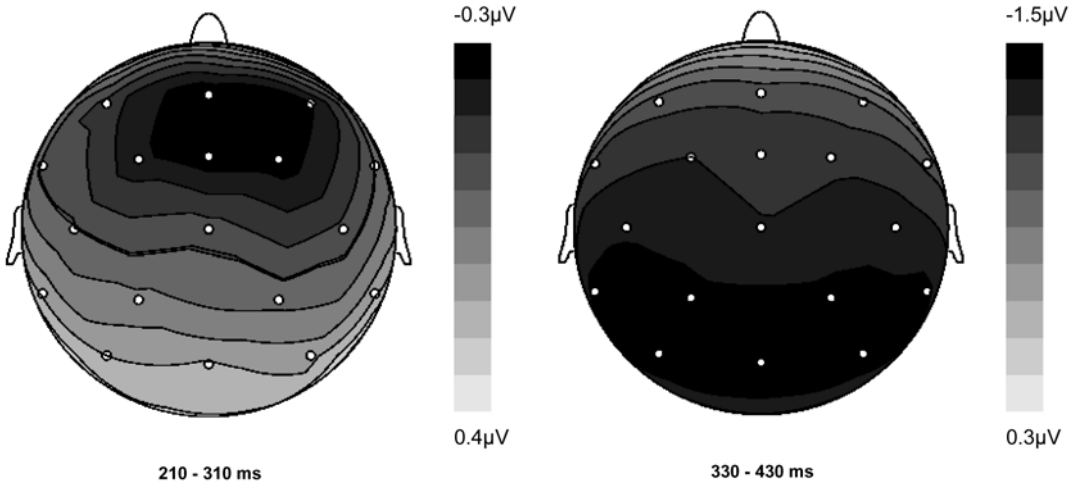

Figure 2

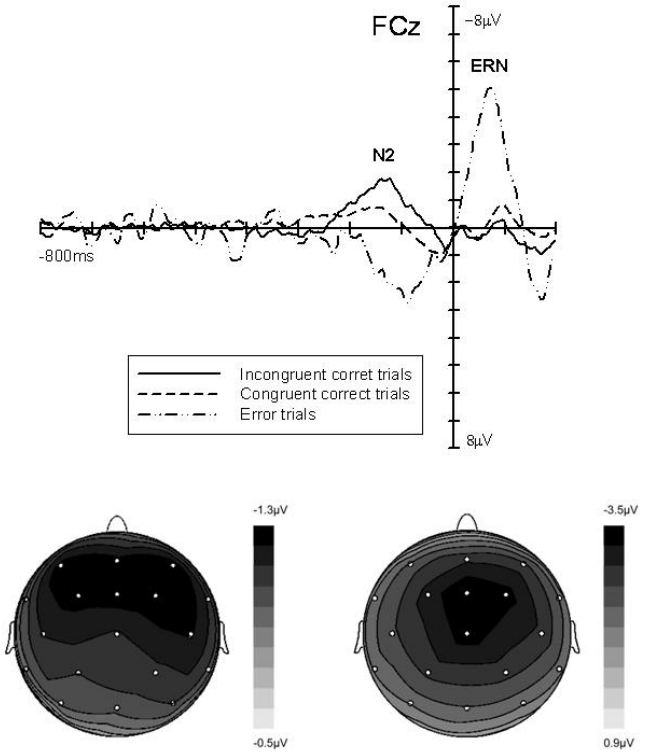
FCz
-8µV
ERN
N2
-800ms
Incongruent corret trials
Congruent correct trials
Error trials
8µV
-1.3µV
-0.5µV
-3.5µV
0.9µV

Figure 3

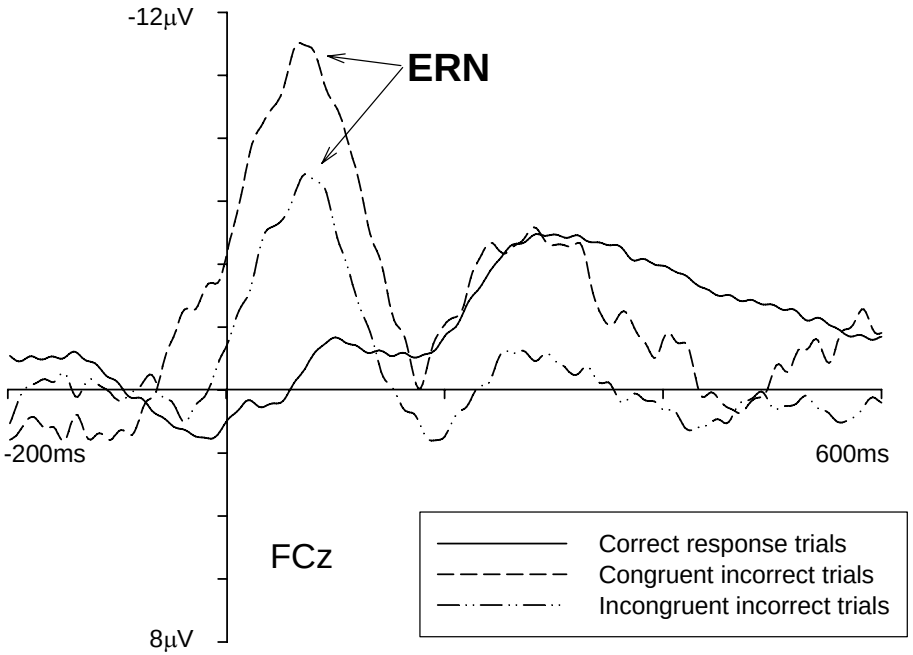
-12μV
ERN
-200ms
600ms
FCz
8μV
Correct response trials
Congruent incorrect trials
Incongruent incorrect trials

Figure 4