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RESEARCH ARTICLE

Multisensory gain within and across hemispaces in simple and choice reaction time paradigms

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Abstract Recent results on the nature and limits of multisensory enhancement are inconsistent when stimuli are presented across spatial regions. We presented visual, tactile and visuotactile stimuli to participants in two speeded response tasks. Each unisensory stimulus was presented to either the left or right hemispace, and multisensory stimuli were presented as either aligned (e.g. visual right/tactile right) or misaligned (e.g. visual right/tactile left). The first task was a simple reaction time (SRT) paradigm where participants responded to all stimulations irrespective of spatial position. Results showed that multisensory gain and coactivation were the same for spatially aligned and misaligned visuotactile stimulation. In the second task, a choice reaction time (CRT) paradigm where participants responded to right-sided stimuli only, misaligned stimuli yielded slower reaction times. No difference in multisensory gain was found between the SRT and CRT tasks for aligned stimulation. Overall, the results suggest that when spatial information is task-irrelevant, multisensory integration of spatially aligned and misaligned stimuli is equivalent. However, manipulating task requirements can alter this effect.

Keywords Multisensory · Visual · Tactile · Simple reaction time · Choice reaction time · Redundancy gain (RG)

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Introduction

The brain has a remarkable ability to integrate multiple sensory inputs in order to produce coherent perceptions and behaviours. Because multisensory stimuli are detected faster than unisensory stimuli, the simultaneous stimulation of two or more sensory modalities facilitates behaviour (Hershenson 1962; Todd 1912). Quicker reaction times (RT) for multiple over single stimuli, called redundancy gain (RG), have long been reported (e.g. Raab 1962). RG can be explained by two main approaches: the race model and the coactivation model. The race model (Miller 1982), also called the probability summation model, proposes that individual sensory information is processed through independent channels. Average detection speed is determined by the latency of a single detection process in single stimulus trials and by the fastest stimulus detection process in multisensory trials. In the case of multiple stimuli, only the fastest stimulus is required to reach the activation criterion to trigger a motor response. Hence, increasing the number of channels increases the probability that the RT of the fastest channel will be faster than the mean RT. Statistically, RTs for multisensory stimuli are predicted to be faster than RTs for single stimuli. Alternatively, the coactivation model postulates that when RT facilitation exceeds the race model's prediction, a neural mechanism integrates activations from different channels to trigger the motor response, resulting in greater redundancy gain. A violation of the race model therefore indicates neural integration (Miller 1982). However, note that race model violation is not a pre-requisite for neural interaction because non-linear interactions were observed even when the race model was satisfied (Murray et al. 2001; Sperdin et al. 2009). Furthermore, non-linear brain responses were also observed in passive subjects (Foxe et al. 2002) and in anaesthetised animals (Schroeder and Foxe 2002; Schroeder et al. 2001).

The spatial principle, also called the spatial rule, is particularly relevant in multisensory integration. It states that multisensory interactions are dependent on the overlap between receptive fields that respond to stimuli. Therefore, facilitative interactions can be observed even when the external coordinates of the stimuli are misaligned, provided that the responsive neurons contain overlapping representations or sufficiently large receptive fields (Wallace and Stein 2007; Stein and Meredith 1993). If the stimuli are derived from spatially disparate locations, such that one stimulus falls outside of the neuron's receptive field, either no interactions or even response depression may occur. For example, pioneering studies on multisensory integration in the superior colliculus (SC) of cats showed that spatially congruent stimuli tend to produce increased firing rate in neurons, whereas spatially discordant stimuli produce suppressive interactions (e.g. Meredith and Stein 1986). Several studies in humans showed that multisensory interactions are subject to spatial limitations. Within certain limits, facilitative effects on RTs were observed with spatially aligned and spatially disparate stimuli presented across hemispaces (Harrington and Peck 1998; Forster et al. 2002; Diederich et al. 2003). Studies on multisensory integration also reported spatial congruency effects on RTs (slower RTs for misaligned than aligned stimuli). However, most of these studies addressed attentional factors such as directing attention to a specific sensory modality (Diederich et al. 2003; Macaluso et al. 2005) or body part (Sambo and Forster 2009). Recent studies using auditory–somatosensory stimuli reported multisensory interactions regardless of spatial alignment (Murray et al. 2005; Zampini et al. 2007; Kitagawa and Zampini 2005), suggesting that the caudal medial auditory belt cortex may play an important role in these multisensory interactions, as it contains large bilateral auditory receptive fields that respond to the full 360° azimuth. In fact, early multisensory interactions occurred in auditory association areas regardless of spatial congruence for auditory-tactile stimuli (Murray et al. 2005; Foxe et al. 2002), suggesting a direct influence between sensory-specific areas. In contrast to auditory regions that contain complete representation of auditory space, somatosensory and visual regions contain representations of the contralateral space, as they receive inputs predominantly from the contralateral side (Fitzpatrick 2008). Therefore, congruent visuotactile stimuli are processed by one hemisphere, whereas incongruent or bilateral combinations may require interhemisphere interaction in order to merge sensory information. For instance, visual and tactile sensory-specific cortical activity appears to depend on the spatial congruency of the stimuli, with stronger activation when both visual and somatosensory stimuli are presented at the same contralateral location (Macaluso et al. 2000, 2005; Sambo and Forster 2009). No studies to date have reported early low-level interactions between misaligned visuotactile stimuli. Given that early low-level multisensory interactions between auditory and somatosensory signals appear to be linked to faster behavioural performance (Sperdin et al. 2009, 2010), the integration of visuotactile stimuli may be modulated by the stimuli's spatial congruency. Forster et al. (2002) reported multisensory gain in reaction times with spatially disparate visuotactile stimuli, but did not compare aligned and misaligned conditions. To our knowledge, no study has directly assessed race model violation for spatially congruent and incongruent visuotactile combinations. We therefore compared race model violation and multisensory gain (MG) obtained with spatially aligned (both stimuli in the same hemispace) and misaligned (stimuli presented across hemispaces) visuotactile combinations in a paradigm where the spatial position of the stimuli was task irrelevant (Task 1).

The variability of the findings in the literature also suggests that task requirements may influence the extent of multisensory interaction. In fact, it is thought that MG might be modulated by the relevance of the spatial information in the task demand (Spence and MacDonald 2004). Therefore, we also tested the hypothesis that the nature of the task may modulate multisensory enhancement by determining whether MG differed between a simple reaction time paradigm (SRT; Task 1) and a choice reaction time paradigm (CRT; Task 2) using the same stimuli for both tasks. Spatial location of the stimuli was task irrelevant in Task 1 and task-relevant in Task 2.

Method

Participants

Twenty right-handed (Oldfield 1971) volunteers participated in the experiment (10 females, 10 males). Age ranged between 19 and 34 years. All participants reported normal tactile perception and normal or corrected to normal vision. The study was approved by the local ethics committee of the Université de Montréal, and all subjects gave their written informed consent prior to participating.

Stimuli and procedure

The experiment was conducted in a dark, sound-attenuated room. Participants sat in a chair with their head on a chin rest. Tactile stimuli were trains of five 1-ms biphasic square wave pulses delivered every 25 ms (40 Hz for 100 ms) applied to the skin using disposable ring electrodes (Nicolet Biomedical, Madison, USA). Electrodes were placed around the proximal and distal interphalangeal joint of the index finger of each hand. Stimuli were generated using a

Grass S88 dual output stimulator connected to each hand through a PSIU6 isolation unit (Grass, Astro-Med, West Warwick, USA). Due to the substantial interindividual and intermanual (at the individual level) differences in sensitivity to electrocutaneous stimuli, stimulus intensity was individually calibrated between hands to equate perceived left and right intensity and to obtain prominent but comfortable (not painful) stimulation during the task. Visual stimuli consisted of a white circle subtending 1° of visual angle presented against a grey background and to the right or left of a central fixation cross at 7.5° of eccentricity. This presentation was to ensure that visual stimuli evoked activity in the contralateral visual cortex only (Sereno et al. 1995). Visual stimuli were projected at 57 cm from the participant's head for 100 ms. Multisensory stimuli were obtained by simultaneously presenting visual and tactile stimuli. Stimuli were presented under four unisensory conditions (visual left, visual right, tactile left and tactile right) and four multisensory conditions (visual left/tactile left, visual left/tactile right, visual right/tactile right and visual right/tactile left). Therefore, multisensory stimuli could be either spatially aligned (both stimuli originating from the same location) or spatially misaligned (visual stimuli presented to one side and tactile stimuli presented to the opposite side) (see Fig. 1). Catch trials (10%) with no stimulus were included to control for anticipatory responses.

Participants had to place their hands on two small response boxes placed 30 cm from the body and 8 cm from the right and left of the body's midline. Visual stimuli were projected directly next to the stimulated area of the index finger of each hand to ensure maximum spatial congruency (see Fig. 1). Participants were asked to respond as fast as possible by pressing a button on the box with their right thumb. Stimuli were delivered and reaction times were recorded using Presentation software (Neurobehavioral Systems Inc.).

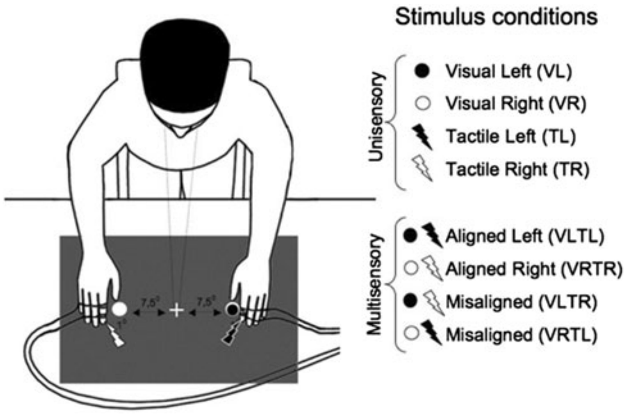

Fig. 1 Schematic view of the experimental setup and stimulation conditions. Electrocutaneous stimulations were delivered to the index finger of each hand, and visual stimuli were projected next to the stimulated area of the fingers. A total of eight stimulation conditions were used: four unisensory and four multisensory

In Task 1, an SRT, participants were required to make speeded responses to all stimuli, irrespective of their spatial position. In Task 2, a CRT paradigm, participants were asked to respond to all stimuli appearing in the right hemispace and to ignore stimuli appearing in the left hemispace (visual left, tactile left and left visuotactile stimuli). Task order was counterbalanced across participants. Participants completed eight blocks of 135 experimental trials with each stimulus configuration presented 15 times per block. A total of 60 trials per condition were recorded for each task. Each stimulus presentation was followed by 800 ms of grey background (response period) with a fixation cross in the foreground. The cross then disappeared for 200 ms and reappeared for 200–1,600 ms (random duration) prior to the next stimulus (mean ISI = 2,000 ms; range 1,300–2,700 ms). Participants' gaze was monitored with a camera, and the experimenter ensured that they maintained central fixation during the tasks. Participants were asked to respond as quickly as possible and to refrain from anticipatory responses.

Data analysis

Only RTs between 100 and 1,000 ms post-stimulus were analysed. To test for multisensory interactions in the RT data, we determined whether the RT obtained in bimodal conditions exceeded the statistical facilitation predicted by probability summation using Miller's race model of inequality (Miller 1982). Race model inequality was analysed using RMITest software, which implements the algorithm described in detail in Ulrich et al. (2007). This procedure involves several steps. First, empirical cumulative density functions (CDFs) of the reaction time distributions are estimated for each participant and each stimulus condition (auditory alone, tactile alone and bimodal condition). Second, the bounding sum of the two CDFs obtained in the two unimodal conditions (auditory and tactile) is computed for each participant. This estimates each participant's upper boundary for violation of race model inequality. Third, percentile values are calculated for each stimulus condition and bounding sum (the bound) for each participant. We used bin widths of 10% (e.g. Martuzzi et al. 2007; Sperdin et al. 2009) to obtain a good compromise between a sufficient number of bins to observe violation of race model inequality and an excessive number of bins, which would require a large number of reaction times in each condition to compute race model inequality. Fourth, for each percentile, the bimodal condition and the bound are compared using a two-tailed *t*-test. If significantly faster RTs in bimodal condition than in bound condition are observed at any percentile, it can be concluded that the race model cannot account for facilitation in the redundant signal condition, supporting multisensory integration. MG was calculated as the decrease (in percent) of the mean RT obtained in multisensory condition when compared with the mean estimated RT for the race model bound. MG indices were obtained for each percentile of the reaction time distribution and submitted to repeated measures analysis of variance (ANOVA).

Results

In both tasks, participants detected an average of 98.8 ± 1.1% of all visual targets, 95.8 ± 4.5% of all tactile stimuli and 98.5 ± 2% of all multisensory combinations. To test for multisensory interactions in the RT data, we investigated whether the RT obtained in bimodal conditions exceeded the statistical facilitation predicted by probability summation using Miller's race model of inequality (Miller 1982). We observed significant violation of the race model prediction for all Task 1 bimodal conditions, irrespective of spatial alignment (see Fig. 2). The RT obtained significantly exceeded the model prediction for the 10th–70th percentiles for both the right- and left-aligned condition ($P = .001$ to $P \leq .029$), the 10th–70th percentiles in visual left/tactile right condition ($P = .001$ to $P \leq .031$) and the 10th–60th percentiles in visual right/tactile left condition ($P = .001$ to $P \leq .009$). For Task 2, the model prediction was violated for the 10th–80th percentiles of the reaction time distribution in aligned right condition ($P = .001$ to $P \leq .037$). Because participants had to react to right-sided stimuli only in Task 2, the race model could be calculated for the aligned right condition only.

We conducted an initial ANOVA to determine whether the mean MG for bimodal stimuli was modulated by the spatial location of each unisensory constituent in Task 1. Within-participant factors were the alignment (aligned and misaligned) and spatial location of visual stimuli (left or right) for common significant percentiles (10th to 70th). The results revealed no significant differences for the alignment factor ($F_{(1,19)} = .627$; NS), demonstrating a similar decrease percentage in RT for the aligned and misaligned condition. No significant main effect was found for the spatial location of visual stimuli ($F_{(1,19)} = 1.01$; NS). As expected, a significant main effect of percentile ($F_{(6,114)} = 6.01$; $P \leq .001$) was found, resulting from the reaction time distribution probability among participants. No interactions were found between alignment and visual side ($F_{(1,19)} = .246$; NS), alignment and percentiles ($F_{(6,114)} = .254$; NS), visual side and percentiles ($F_{(6,114)} = .601$; NS) or between all three factors ($F_{(6,114)} = .423$; NS).

To assess a potential difference between SRT and CRT (see Fig. 2b), we conducted a second ANOVA on the aligned right (VRTR) condition in Task 1 and Task 2 with task (Task 1 and Task 2) and common significant percentiles (10th to 80th) as within-participant factors. No main effect of task ($F_{(1,19)} = .846$; NS) was found, indicating that the MG for this specific condition was not modulated by task demand. As expected, a significant main effect of percentiles ($F_{(7,133)} = 15.40$; $P \leq .001$) was found, resulting from the reaction time distribution probability among participants. Finally, no interactions between task and percentiles ($F_{(7,133)} = .900$; NS) were found.

Because the MG could not be calculated for the incongruent stimuli configurations, we conducted further analyses to assess RT differences between all conditions of Task 2. Thus, we ran a 1 × 5 ANOVA with stimulus type (visual right, tactile right, aligned right visuotactile combination and both misaligned conditions) as the within-participant factor. A significant main effect of stimulus type ($F_{(1,19)} = 40.49$, $P < .001$) was obtained. Post-hoc comparisons revealed an advantage for multisensory stimuli but only for the aligned configuration (all $P \leq .001$). For the misaligned conditions in Task 2, RTs for the visual left/tactile right (VLTR) condition were significantly slower than RTs for all other conditions (all $P \leq .048$), indicating a disadvantage for multisensory stimuli in this condition (see Fig. 3). No significant difference was found between the visual right/tactile left (VRTL) and unisensory condition.

Discussion

The main goal of this study was to investigate whether race model violation and MG were the same for spatially aligned and misaligned pairs of visuotactile stimuli. A critical finding in Task 1 was that all multisensory conditions clearly violated the race model. Furthermore, no significant MG differences were found between aligned and misaligned condition, demonstrating that RTs to multisensory stimuli were equally facilitated in both conditions. To our knowledge, this is the first behavioural demonstration of equivalent visuotactile interactions across spatial configurations using race model violation as a criterion. RTs that violate the race model can be attributed to the convergence and interaction of neural responses to stimuli in a behaviourally facilitative manner (Murray et al. 2001). Recent studies by Sperdin et al. (2009, 2010) supported this by showing that early-latency low-level interactions might be linked to faster performance on a simple detection task. Using auditory–somatosensory stimuli, they demonstrated that only trials producing RTs in excess of simple probability summation showed early non-linear neural interactions, whereas both fast and slow trials displayed later non-linear effects.

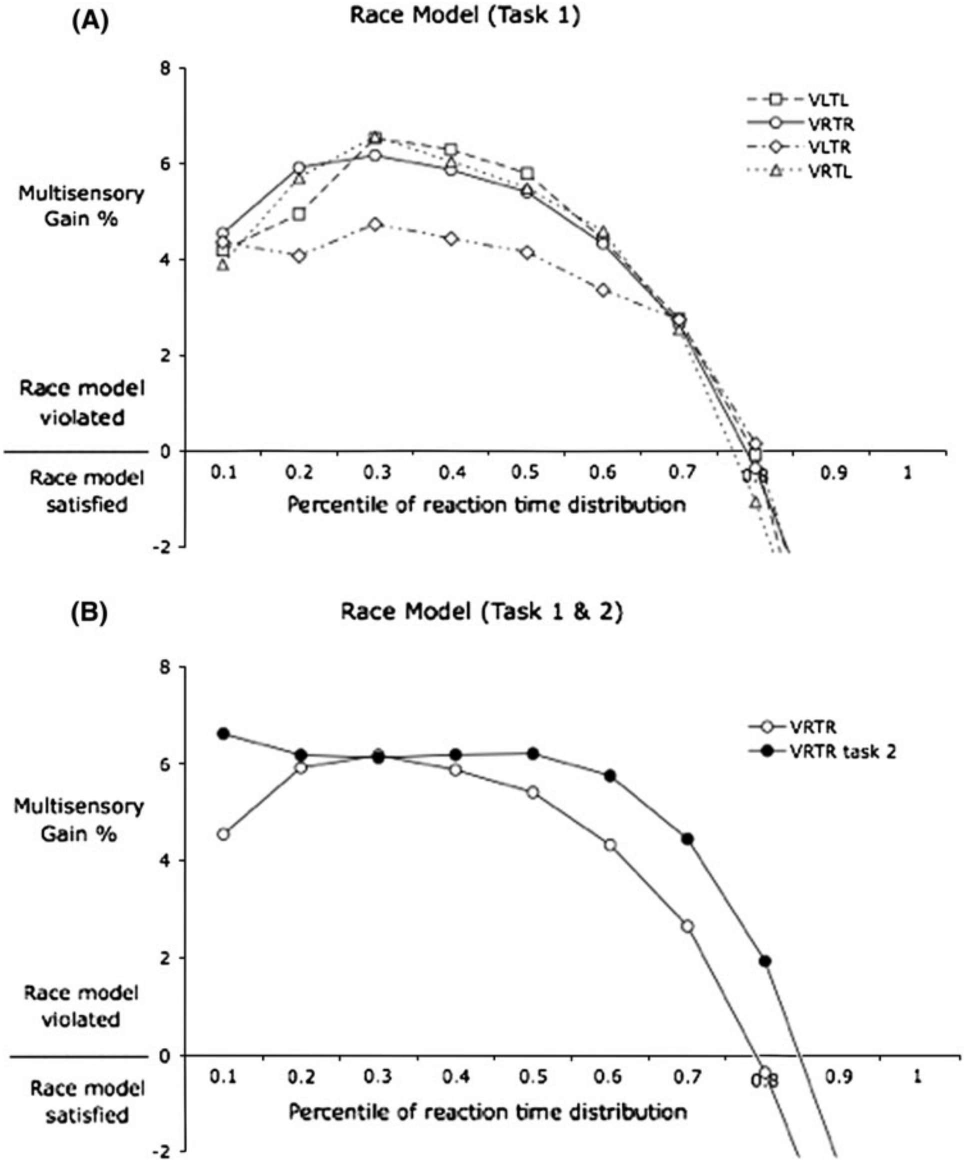

Fig. 2 Test for violation of race model inequality (Miller 1982). The multisensory gain (MG) represents the percent decrease of the mean RT obtained for the multisensory condition compared with the mean estimated RT for the race model bound. MG was calculated for each percentile of the reaction time distribution. Bin widths of 10% were used. Positive values on the *Y*-axis indicate race model violation, and negative values indicate race model satisfaction. **a** The race model of inequality was significantly violated for all conditions of Task 1, irrespective of spatial alignment. **b** The race model was violated over a similar range of the reaction time distribution in Task 1 (SRT) and Task 2 (CRT)

Electrophysiological studies on the encephalon in humans and animals have revealed a multitude of cortical and subcortical brain structures where visual and tactile inputs converge and interact. In animals, the most extensively described structure is the superior colliculus, a midbrain region involved in gaze control and orientation (Stein 1998; Meredith and Stein 1986). As mentioned above, neurophysiological studies on the superior colliculus observed facilitative interactions when stimuli were misaligned in their external coordinates, provided that the responsive neurons contained overlapping representations or sufficiently large receptive fields (Wallace and Stein 2007; see Stein and Stanford 2008, for a review). Unfortunately, few studies have considered the effect of spatial disparity on multisensory integration in other brain areas.

Our results are consistent with those of other studies that found no modulation of multisensory integration for aligned or misaligned auditory–somatosensory stimuli (Murray et al. 2005; Zampini et al. 2007). Furthermore, based on electrophysiological data, Murray et al. (2005) suggested that facilitative multisensory interactions occur at identical latencies and via indistinguishable mechanisms when stimuli are presented at the same position or on opposite hemispaces. They also proposed that the caudal medial auditory belt cortex contains large bilateral auditory receptive fields that respond to the full 360° azimuth. Another electrophysiological study reported similar behavioural findings using audiovisual stimulus pairs. Despite the absence of spatial modulation of reaction time data, they reported overlapping but distinctive patterns of multisensory neural integration between spatially aligned and

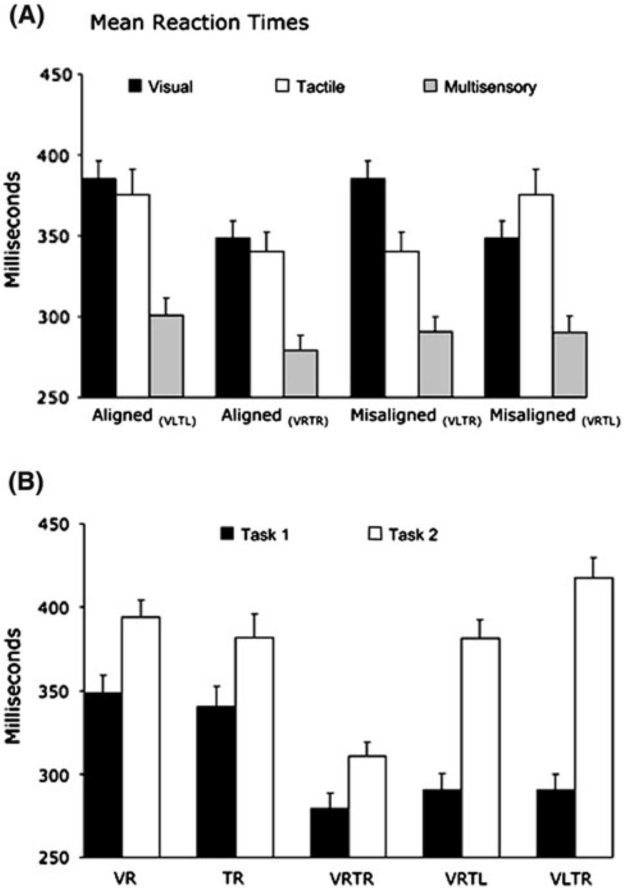

Fig. 3 **a** Mean reaction time (in milliseconds) and standard error for multisensory pairs (*grey bars*) and corresponding visual (*black bars*) and tactile (*white bars*) unisensory stimuli in Task 1. *Capital letters* refer to the modality and spatial location of each stimulus. When participants were asked to respond to all stimuli, irrespective of spatial location, multisensory facilitation was found for all multisensory conditions. **b** Mean reaction time for common conditions of Task 1 (*black bars*) and Task 2. When participants were asked to respond to stimuli presented on the right side only, the results show facilitative interaction for the aligned (VRTR) condition only and a disadvantage for one misaligned condition (VLTR)

misaligned stimulus pairs (Teder-Sälejärvi et al. 2005). On the other hand, visuotactile neural interaction has been reported for spatially congruent stimulus configurations only (Macaluso et al. 2005; Zimmer and Macaluso 2007; Sambo and Forster 2009).

In a recent study, Macaluso et al. (2005) used visuotactile stimuli to investigate whether crossmodal spatial-congruence effects depend on task relevance in sensory-specific cortices. They found that activity in visual and somatosensory areas was modulated by the stimuli's spatial congruence, with stronger activation when both stimuli were presented at the same spatial location. Importantly, this effect was found irrespective of which modality was task relevant. Zimmer and Macaluso (2007) demonstrated that, in either a visual attention or working memory task, a tactile stimulus presented at the same location as a visual target increased activity in the contralateral occipital cortex compared to incongruent combinations. While performing the primary working memory task, participants were asked to perform a secondary visual discrimination task in which task-irrelevant tactile stimulations were presented at spatially congruent or incongruent locations. While performing the visual attention task, they were presented with task-irrelevant congruent or incongruent visuotactile stimulus pairs. Results showed that crossmodal effects were unaffected by both the attentional and working memory task, suggesting that visuotactile spatial congruency in the visual cortex does not depend on available visuospatial and memory resources. Another study reported that spatially disparate visuotactile stimuli failed to produce behavioural or activity enhancement in the somatosensory area even when stimuli were presented in the same hemifield (Sambo and Forster 2009). On the other hand, behavioural enhancements were found in a similar paradigm where the distance between the stimuli was shorter (Forster et al. 2002). Overall, these findings suggest that low-level visuotactile interactions might be mediated by direct anatomical connections between unisensory areas (Foxe and Scrhoeder 2005; Rockland 2004). However, this explanation accounts for spatially congruent stimuli only. Due to their lateralized cortical representations, interactions between vision and touch are less likely to occur via direct anatomical connections between unisensory areas when stimuli are presented across hemifields. Therefore, if spatially congruent and spatially disparate stimuli are mediated by partially segregated pathways, our results suggest that these pathways are equally effective for behavioural performance. The present findings on visuotactile stimuli would be relevant for determining whether the crossed anatomical pathways and the corresponding representations of these sensory systems could yield the same behavioural patterns as audiotactile and audiovisual multisensory signals. Recent studies demonstrated that auditory–somatosensory interactions were modulated by the specific body part that was stimulated (see Kitagawa and Spence 2006, for a review). For example, Tajadura-Jiménez et al. (2009) reported faster RTs for aligned than misaligned stimuli when somatosensory stimuli were delivered to the participants' heads. However, they observed no spatial modulation when somatosensory stimuli were delivered to the participants' hands. Our results might have differed if the somatosensory stimuli were delivered to another body part (e.g. the head), possibly revealing a spatial modulation effect. In the present study, tactile stimuli were delivered to both hands, whereas the responses were produced with the right hand only. Because there was no difference in MG for all multisensory conditions, the effect of inter-hemispheric transfer time did not appear to modulate multisensory enhancement. However, it is possible that using only the right hand to respond marginally modulated MG for misaligned conditions.

Our results also show that the race model prediction was exceeded over a similar reaction time distribution in the CRT and SRT (see Fig. 2b). Contrary to Hecht et al. (2008), MG demonstrated the same behavioural enhancement for SRT and CRT, suggesting no further advantage for multisensory processing in more demanding tasks such as the CRT paradigm. In Task 2, with both unisensory components task relevant (VRTR), MG was not modulated by task demand even though this task involved more no-go than go trials. Note that due to the experimental paradigm, the two tasks could only be compared for one stimulation condition (VRTR). MG for the other conditions in Task 2 was inaccessible due to the absence of responses for left unisensory stimuli. A recent study investigated whether task-relevant stimuli would impact detection RTs for spatially aligned and misaligned auditory–somatosensory stimuli (Sperdin et al. 2010). In a detection RT task with unisensory, spatially aligned and misaligned auditory–somatosensory stimuli, participants were retrogradely probed (one-third of trials) on the location of a given stimulus in a given sensory modality. Results showed that detection RTs were facilitated for both aligned and misaligned multisensory stimuli relative to their constituent unisensory condition. In other words, task-relevant spatial location of stimuli had no affect on detection RTs. However, whereas unisensory and aligned multisensory stimuli yielded highly accurate discrimination performance, misaligned auditory–somatosensory stimuli interfered with the participants' ability to report the spatial location of either constituent unisensory stimulus. The discrepancy between these and our results may be explained by the fact that auditory–somatosensory integration appears to be inherently less spatial than other sensory combinations (Kitagawa and Spence 2006). Nevertheless, it suggests that the task-relevance of spatial information is not a salient factor in observing spatial modulation of auditory–somatosensory integration.

Different behaviours were observed using the same stimuli under conditions of task-irrelevant (Task 1) versus task-relevant (Task 2) spatial information. The absence of contingencies in Task 1 allowed observing visuotactile interactions without the influence of top-down, attention-related or task-related constraints (Spence et al. 1998). Results on Task 2 also support the view that task requirements may influence the spatial limitations of multisensory integration (Talsma et al. 2007). Few explanations have been proposed to account for this effect. For instance, Murray et al. (2005) suggested that higher-order cognitive and/or attentional processes might act as a top-down influence on multisensory interactions. This would involve either dynamic shifts of the spatial representations or strategies that emphasize on the stimuli's temporal aspect over spatial location.

In the CRT, with both stimuli task relevant (visual right/tactile right; VRTR), reaction times exceeded the race model prediction. However, one misaligned condition (visual left/tactile right; VLTR) yielded slower RTs than the unisensory conditions, indicating multisensory inhibition (see Fig. 3). Therefore, when participants responded to a right tactile target, the left visual stimulation interfered with performance. On the other hand, no interference was seen for task-irrelevant tactile stimulation when participants responded to a visual target. This difference may be attributed to visual dominance in multisensory paradigms (Spence et al. 2004; Colavita 1974; McGurk and MacDonald 1976). For example, Hecht and Reiner (2009) reported that haptic and auditory signals are more likely to be undetected when combined with a visual signal. The results on both tasks are therefore consistent with prior findings indicating that behavioural advantage for multisensory processing occurs when both modalities are fully attended (Talsma et al. 2007). Overall, the results on Task 2 suggest that stimuli presented at an unattended location are not beneficial to the task. Participants may also have attempted to filter out irrelevant sensory information instead of integrating it with the relevant stimuli, resulting in a behavioural cost when processing misaligned multisensory stimuli.

In summary, this study contributes to our understanding of multisensory integration in humans. First, we demonstrated race model violation for spatially congruent and incongruent visuotactile stimuli when the spatial position of the stimuli is task irrelevant. Furthermore, MG results indicated that RTs are equally facilitated for aligned and misaligned stimuli, suggesting that both conditions yield the same behavioural enhancement. Second, we demonstrated that the task constraint (SRT or CRT) does not modulate the MG for stimuli that are relevant for both task types. Third, results showed that both multisensory enhancement and inhibition can be obtained using the same physical stimuli, supporting the idea that multisensory integration is modulated by task requirements and the relevance of spatial information.

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