

David I. Shore · Nevena Simic

Integration of visual and tactile stimuli: top-down influences require time

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Abstract In a visuotactile congruency task, a distracting flash of light presented near a tactile target can influence speeded judgments of tactile location. Localization of the tactile target is more rapid when the elevation of the visual distractor is congruent with the tactile stimulus than when it is incongruent. The goal of the present study was to examine the degree of control that can be exerted on the process proposed to integrate the visual and tactile stimuli. To this end, the proportion of spatially congruent items was manipulated across blocks of trials. A robust congruency effect was observed across three experiments. There was no effect of proportion congruency (varied between 75 and 11% congruent) when the visual event was presented only 30 ms prior to the tactile event. When this lead-time was increased to 100 ms there was a significant increase in the congruency effect, for errors, in the high proportion congruent conditions (experiment 3). We conclude that with sufficient lead-time, top-down influence can be exerted in this task, however, when presented at near simultaneity, visuotactile integration is independent of top-down effects.

Keywords Visual stimuli · Tactile stimuli · Congruency · Visuotactile integration

vast fronto-parietal network appears to be responsible for the rapid and automatic integration of these sensory sources (Graziano 1999; Kaas and Collins 2004). Within this network of regions there are multisensory bimodal neurons that respond to both visual and tactile information in spatial register (Graziano and Gross 1993). That is, the visual receptive field of the cell moves along with the tactile receptive field as the arm is placed in different postures. Interestingly, when an animal uses a tool for reaching, the visual receptive field can expand to include the tip of the tool (Ishibashi et al. 2004). In humans, functional MRI has revealed a similar network of activations when observers are presented with a tactile stimulus to a digit that is in clear view (Lloyd et al. 2003). Critically, if the eyes are closed, this complex network is not recruited and instead a small area of activation is seen in the IPS contralateral to the spatial location of the limb. That is, with the eyes closed and the limb placed across the body midline, it is ipsilateral IPS that is activated by the tactile stimulus whereas with the eyes open, the more appropriate contralateral IPS and fronto-parietal network is seen activated. These data provide a link between the non-human and human data at the network level, but cannot show the behavioural consequences of the bimodal neurons reported in the macaque.

Introduction

Effective interaction within our environment relies on accurate integration of visual and tactile information. A

Visuotactile congruency task

First described by Pavani et al. (2000), the visuotactile congruency task has been proposed to provide a behavioural index for the operation of bimodal sensory-motor neurons in the human brain (Maravita et al. 2003; Holmes and Spence 2004). In this task, observers hold two foam cubes, one in each hand, on which are mounted two tactile vibrators (on the top and bottom of the cube) along with two light emitting diodes (LEDs) adjacent to the vibrators (see Fig. 1). The observers' task is to identify the elevation of the tactile stimulus (top or bottom) while ignoring the near-simultaneous visual

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D. I. Shore (✉) · N. Simic
Multisensory Perception Laboratory,
Department of Psychology Neuroscience & Behaviour,
McMaster University, 1280 Main Street West,
Hamilton, Ontario, L8S 4K1, Canada
E-mail: dshore@McMaster.ca
Tel.: +905-525-9140
Fax: +905-529-6225

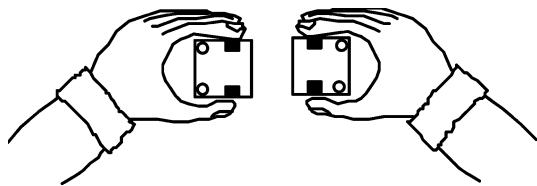


Fig. 1 Schematic representation of stimulus configuration. *Black squares* represent tactile vibrators. *White circles* represent LEDs. One cube was held in each hand. Each cube had two vibrators (*top* and *bottom*) and two adjacent LEDs

events. When the visual and tactile events occur at the same location (same hand, same elevation), performance is fast and accurate whereas if the visual event occurs on the same hand, but at the opposite elevation, performance is slow and inaccurate. When the stimuli are on opposite hands, performance is only mildly affected by the relative positioning of the tactile and visual stimulation. The link between this task and the operation of bimodal neurons in prefrontal and/or parietal cortices rests on the similarity of the effects observed in humans (Maravita et al. 2003) and those seen in single cell recording experiments in macaque (Graziano and Gross 1993).

Using this task, researchers have demonstrated a spatial visuotactile correspondence similar to that seen with the bimodal neurons in primate cortex. That is, as the visual event is moved away, in space, from the tactile stimulation, the level of interference declines (Spence et al. 2001a). Presenting the visual events at the end of a tool that had been used by the observer, increased the interference observed (Maravita et al. 2002; Holmes et al. 2004). It is as if the visual receptive field mapped onto the tactile stimulus on the hand has moved to the tip of the tool, just as observed with the bimodal neurons in the macaque (Ishibashi et al. 2004). These correspondences support the link between the bimodal neurons observed in the non-human primate and the behavioural task used in humans. Specifically, “these results are consistent with the extant neurophysiology of the visuotactile representation of 3-D peripersonal space seen in primates (Spence et al. 2004, pp. 185)”. It is important to note that this link represents a theoretical claim that needs to be tested—the present experiments provide further support of this claim. Specifically, if the homologues of these bimodal neurons in the human are sub-serving the visuotactile congruency task and these neurons represent an early sensory representation, then it may be that the process producing the interference is immune from top-down strategic influences. The experiments presented here test the relative independence of performance in this task from top-down influences.

Controlled versus automatic processes

The distinction between controlled and automatic processes in human performance represents a core

assumption of modern cognitive psychology (Egeth and Yantis 1997). Although the dichotomy is a weak one without a clear delineating boundary, it is useful as a rubric for understanding the relative influence of top-down control over bottom-up stimulus processing (Klein and Shore 2000). Top-down influence, in the present context, does not imply voluntary consciousness, but rather the role of expectation from the experimental context on the processing of the current stimulus. This area of selective attention has a rich history in supporting this segregation of processing (Posner and Snyder 1975). One hallmark of controlled processing is its sensitivity to the relative proportions of different target events (cf. Gratton et al. 1992). Typically, the proportion of congruent items in a conflict experiment (e.g. Stroop 1935; Logan and Zbrudoff 1979) modulates the size of the interference effect. With many congruent trials, the interference effect was larger than with few congruent trials. Apparently, when there are few congruent items, observers engage a more controlled strategy, whereas with many congruent items, they relied more on bottom-up processing. This top-down influence can be considered a form of behavioural monitoring, most likely instantiated in the anterior cingulate cortex (Swik and Turken 2002).

With other, more automatic, stimulus–response mappings the proportion of congruent items does not seem to have any effect. For example, Posner and Snyder (1975) used a letter matching task and provided observers with a pre-cue that was the same as the target letters (congruent trial), different than the target letters (incongruent) or not related to the target letters (a plus sign; neutral trial). Congruent items led to faster reaction times than neutral items, regardless of the proportion of congruent trials (80 versus 20%), indicating that this benefit was independent of top-down influence. The present experiments apply this logic to the visuotactile congruency task to see if the interference observed from visual events on tactile responding is sensitive to top-down control resulting from probability manipulations.

In the present experiment, the visuotactile congruency task was tested with varying proportions of congruent items. If the mapping of visual stimulus onto a tactile representation can be influenced by top-down control, then there should be a modulation of the congruency effect by this manipulation. Specifically, in the blocks with a high proportion of congruent trials, there should be a larger overall congruency effect whereas with a low proportion of congruent trials, the overall difference should be smaller. On the other hand, if top-down influence (cf. Posner and Snyder 1975) cannot affect performance on this task, then there should be no difference between the blocks of trials.

Experiment 1

Each observer ran in two sets of blocks with either 75% of the trials congruent or 25% of the trials congruent. If

top-down control can be exerted in this task, then there should be a modulation in the size of the congruency effect. Specifically, with higher proportion congruency, there should be more interference than with low proportion congruency (cf. Logan and Zbrodoff 1979).

Materials and methods

Participants

Thirteen observers from the undergraduate subject pool at McMaster University participated in the current study in return for extra course credit or \$10 cash. The average age was 23.3 years, five were male and 12 were right handed. All reported normal or corrected-to-normal vision.

Apparatus

Two sponge cubes each containing two tactile vibrators (Octicon-A bone-conduction vibrators with vibrating surfaces of 16 mm by 24 mm) and two light emitting diodes (LEDs; red, diameter 10 mm) were held, one in each hand. The vibrator was activated at 250 Hz generated by a waveform generator, amplified and gated by a read-relay connected to the parallel port of a 486 compaq computer and controlled by a turbo Pascal 6.0 program. The LED was controlled similarly but consisted of a 5 V DC source. Both stimuli were clearly suprathreshold and no effort was made to match them in amplitude. Each visuotactile pair was placed under the thumb (bottom of the cube) or index finger (top of the cube) of the observer. A central display consisting of four similar LEDs configured in a plus sign configuration (two green LEDs along the horizontal axis and two red LEDs along the vertical axis) was placed 50 cm in front of the observer to provide a point of fixation and feedback concerning performance. The task was performed in a dark, sound attenuated room and earplugs were worn while white noise (70 dB, SPL-A as measured from the observer's head) played from a central speaker cone to completely block any sounds made by the tactile stimuli. Two footpedals were placed under the toe and heel of the right foot for responding.

Stimuli

Stimulation on each trial consisted of the illumination of the LED for 10 ms followed 20 ms later by the activation of the tactile vibrator for 10 ms. The location of the visual and tactile event (top/bottom and left/right) were controlled by the computer and chosen randomly on each trial.

Procedure

Each trial began when the observer placed both their heel and toe down on the footpedals. Following a

delay of 500 ms, the fixation light was illuminated and remained on until the observer responded or 3000 ms elapsed from the onset of the first display item. The first (visual) stimulus was presented between 500 and 1000 ms after the onset of the fixation. The interval was chosen randomly on each trial. The visual event was extinguished after 10 ms, followed by a 20 ms blank interval, and then activation of the tactile vibrator for 10 ms. The participant was instructed to respond as quickly and accurately as possible to the elevation of the tactile stimulus while ignoring the visual stimulus. They lifted their toe to indicate that the tactile event was on the top of the cube (index finger) and their heel if it was on the bottom of the cube (thumb). Once their response was made, or the 3000 ms time elapsed, feedback was provided concerning the accuracy of their performance. A correct response was signalled with the illumination of the green LEDs on the horizontal meridian. An incorrect response was signalled with the illumination of the red LEDs along the vertical meridian. If the observer responded before the presentation of the tactile stimulus, the green and red lights flickered in alternation 10 times for 100 ms each. If the observer failed to respond within 3000 ms, then all four vibrators and all four lights turned on and off repeatedly every 100 ms until they lifted both their heel and toe off the response pedal. This ensured that they remained alert after missing a trial. The next trial began once the observer replaced their heel/toe onto the response pedal.

Upon arriving at the laboratory, the observer was introduced to the overall task, given a handedness questionnaire, and signed an informed consent form. They were brought into the dark room, acquainted with the stimuli, response requirements, and the various forms of feedback. They then completed three blocks of practice trials consisting of 16 trials each. The experimenter remained in the room for the first practice block to further explain the task and answer any questions. For the remaining two blocks, the experimenter left the room and closed the door. Following each block, the observer signalled to the experimenter with a remote buzzer. Between blocks any questions were answered and the general procedure was reviewed. Following the three practice blocks, the observer completed five blocks of 64 trials at either the high (75%) or low (25%) probability congruency (counterbalanced across participants). With high probability congruency there were 48 congruent trials in each block of 64, whereas with low probability congruency, there were only 16 congruent trials. After completing the first block of trials, there were again three practice blocks with the new level of probability and then five blocks of 64 trials. Observers were specifically asked at the end of the experiment if they noticed any relation between the location of the visual and tactile targets within the sets of blocks. None did.

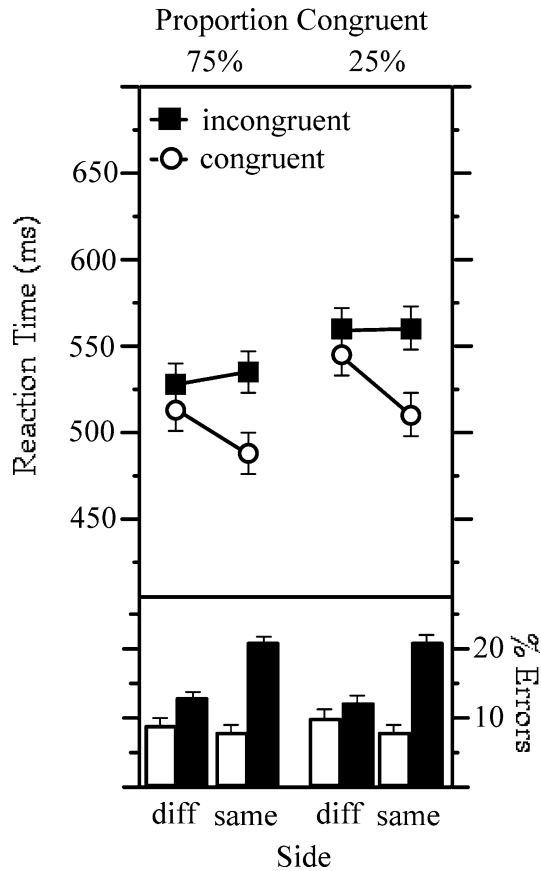


Fig. 2 Reaction time and error rate data from experiment 1. Proportion of congruent trials was either 75% (left panel) or 25% (right panel). Black bars (errors) and squares (RT) represent data from the incongruent (different elevations) trials. White bars (errors) and circles (RTs) represent data from the congruent (same elevation) trials. Error bars represent the 95% confidence interval calculated from the within-observer MSE from the congruency by side interaction term of the ANOVA reported in the text (cf. Loftus and Masson 1994)

Design

There were three within-observer factors in this experiment: congruency (congruent = same elevation; incongruent = different elevation), side (same versus different hands) and proportion congruency (high versus low). The first two factors were administered within-blocks while the last was administered across blocks.

Results

Trials with an incorrect response, a reaction time (RT) less than 200 ms or greater than 2000 ms, or from the first three trials of each block were discarded from RT analysis. Less than 0.5% of observations were excluded as a result of band-passing the RTs. The mean correct RT data were analyzed using a repeated measures analysis of variance (ANOVA) with three factors: congruency (congruent or incongruent), side (same or

different cube), and proportion congruency (75 or 25% congruent). As displayed in Fig. 2 this analysis revealed a main effect of congruency [$F(1,12) = 25.6, P = 0.0002$], caused by faster RTs when tactile and visual stimuli were congruent (i.e. finger vibrations with upper LEDs, or thumb vibrations with lower LEDs) than incongruent (mean = 515 versus 546 ms). There was a main effect of side [$F(1,12) = 6.9, P = 0.02$], with faster RTs when the two stimuli were on the same cube. These two factors entered into a significant interaction [$F(1,12) = 18.3, P = 0.001$] with larger congruency effects when the visual distractor appeared on the same side as the tactile target (49 ms) versus different sides (15 ms). The factor of proportion congruent produced no main effects and did not interact with any other factor. Specifically, the three-way interaction did not approach significance [$F(1,12) < 1.0$]. It is clear from Fig. 2 that the same overall form of interaction was seen for both the 25 and 75% proportion congruent conditions. There is an apparent increase in the overall RT for the 25% condition, however, this was only marginally significant [$F(1,12) = 3.4, P = 0.09$].

Analysis of the error data revealed a similar pattern (see Fig. 2). There was a main effect of congruency [$F(1,12) = 17.3, P = 0.0013$], caused by more errors on incongruent trials (mean = 16.3%) than congruent trials (mean = 8.7%). More errors were committed when the two stimuli were on the same cube (14.2%) compared to when they were on different cubes (10.8%) [$F(1,12) = 9.6, P = 0.0092$] resulting in a speed-accuracy trade-off across the cubes. That is, when the stimuli were on the same cube, observers were faster, but more error prone. This was not true for the interaction of congruency and side [$F(1,12) = 11.1, P = 0.0059$], where the errors showed the same pattern as the RTs with a larger difference between same and different elevations when the stimuli were on the same cube (11.9%) compared to different cubes (3.2%). Again, there was no effect of proportion congruency and this factor did not enter into any interactions with the other two factors. The pattern across the two levels of proportion congruency looks very similar. Again, the three-way interaction was not near significance [$F(1,12) < 1.0$].

Discussion

There was a clear replication of the visuotactile congruency effect observed previously in both RT and errors, with no hint of an influence from the manipulation of proportion congruency. A virtually identical pattern of RTs and errors across the two levels of proportion congruency were observed (see Fig. 2). The ineffectiveness of proportion congruency to modify observers' performance indicates that visuotactile integration in this task is immune from top-down influence. There is a marginal effect of this manipulation since RTs are slightly slower in the mostly incongruent block of trials, however, this slower performance did not produce any

difference in the magnitude of the congruency effect. That is, more monitoring may be going on, however, this is not influencing the amount of interference caused by the visual event.

Experiment 2

It is somewhat surprising that the manipulation of proportion congruency had no effect on the magnitude of the interference caused by the visual event. Before accepting the null hypothesis, it is prudent to further test the claim. In the present experiment, a single, relatively extreme value of proportion congruency was chosen to see if any reduction in the interference effect could be observed. A new group of observers was tested with 89% of the trials being incongruent.

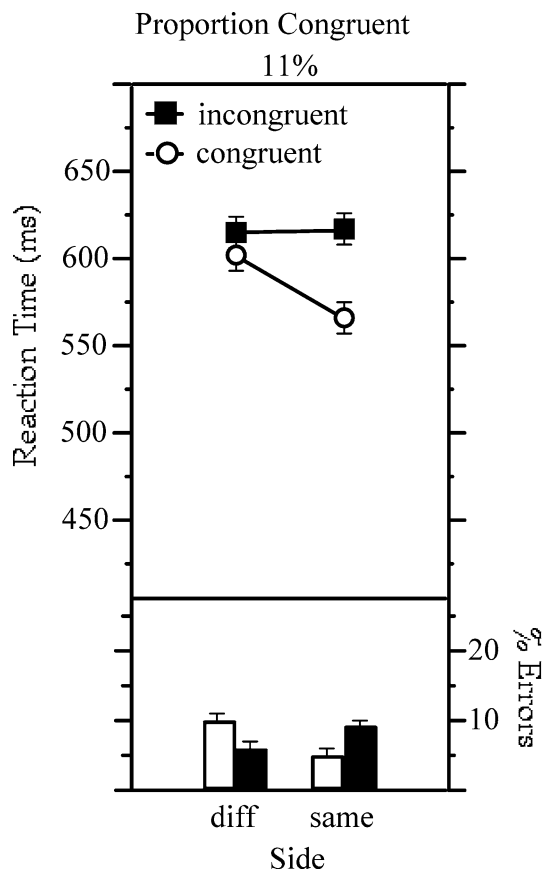


Fig. 3 Reaction time and error rate data from experiment 2. Proportion of congruent trials was 11%. *Black bars* (errors) and *squares* (RT) represent data from the incongruent (different elevations) trials. *White bars* (errors) and *circles* (RTs) represent data from the congruent (same elevation) trials. *Error bars* represent the 95% confidence interval calculated from the within-observer MSE from the congruency by side interaction term of the ANOVA reported in the text (cf. Loftus and Masson 1994)

Materials and methods

Participants

Nine observers from the undergraduate subject pool at McMaster University participated in the current study in return for extra course credit or \$10 cash. The average age was 20.1 years, four were male and eight were right handed. All reported normal or corrected-to-normal vision.

Apparatus and stimuli

These were identical to experiment 1.

Procedure

The general procedure was the same as in experiment 1 with the following exceptions. There were 12 blocks of 64 trials in order to acquire enough data from the 11% of trials with congruent elevations. Of the 64 trials in each block, 56 were incongruent and eight were congruent. Observers were specifically asked at the end of the experiment if they noticed any relation between the location of the visual and tactile targets within the sets of blocks. None did. This is somewhat surprising given the extreme low level of congruency, however, they were told that the visual events were irrelevant.

Design

There were two factors in this experiment: congruency (congruent = same elevation; incongruent = different elevation) and side (same versus different hands) both administered within blocks.

Results

Trials with an incorrect response, an RT less than 200 ms or greater than 2000 ms, or from the first three trials of each block were discarded from RT analysis. Less than 0.5% of observations were excluded as a result of band-passing the RTs. The mean RT data was analyzed using a repeated measures analysis of variance (ANOVA) with two factors (congruency \times side). As displayed in Fig. 3 this analysis revealed a main effect of congruency [$F(1,8) = 12.7$, $P = 0.007$], caused by faster RTs when tactile and visual stimuli were congruent (i.e. finger vibrations with upper LEDs, or thumb vibrations with lower LEDs) than incongruent (mean = 583 versus 616 ms). Again, RTs were faster when the two stimuli appeared on the same cube compared to when they appeared on different cubes [$F(1,8) = 13.6$, $P = 0.006$]. These two effects were modulated by a two-way interaction between congruency and side [$F(1,8) = 22.9$, $P = 0.001$], with a larger difference between same and different elevations when the two stimuli were on the

same cube (52 ms) than when they were on different cubes (13 ms).

Analysis of the error data revealed a similar pattern (see Fig. 3). While there was not a main effect of congruency or side, there was a significant interaction [$F(1,8)=5.3, P=0.05$], with more interference when the stimuli appeared on the same side (4.3%) than when they appeared on different sides (-3.4%; there were more errors in the same elevation condition than the different elevation condition).

Discussion

Despite the extreme level of proportion congruency, there was still a significant congruency effect that was modulated by the distance between the cubes. Indeed, the magnitude of the effect observed with only 11% congruent trials was virtually identical to that observed with 75% congruent trials (see Fig. 2). These data argue for a process that is immune from top-down influence.

Experiment 3

Thus far, there has been no evidence of top-down influence in this task. One way to potentially increase the likelihood of finding such an effect would be to increase the time available for that effect to have an influence (cf. Jonides 1981). To this end, the present experiment replicates experiment 1 increasing the lead-time of the visual event. That is, in experiment 1, the visual event was presented 30 ms prior to the tactile event based on previous work using this task (Pavani et al. 2000). This small interval was presumably introduced to accommodate the slower transduction time for visual stimuli compared to tactile stimuli (cf. Spence et al. 2001b). In the present experiment, this interval between stimulus onsets was increased to 100 ms.

Materials and methods

Participants

Twelve observers from the undergraduate subject pool at McMaster University participated in the current study in return for extra course credit or \$10 cash. The average age was 25.8 years, six were male and ten were right handed. All reported normal or corrected-to-normal vision.

Apparatus and stimuli

These were similar to experiment 1 with the sole difference being an increase in the temporal interval between the offset of the visual event and the onset of the tactile event. The visual event was presented for 10 ms, followed by a 90 ms blank interval, after which time the

tactile stimulus was presented for 10 ms. Thus, the stimulus onset asynchrony (SOA) was 100 ms.

Procedure

The procedure was the same as in experiment 1.

Design

There were three factors in this experiment: congruency (congruent = same elevation; incongruent = different elevation), side (same versus different hands) and proportion congruency (high versus low). The first two factors were administered within-blocks while the last was administered across block sets.

Results

Trials with an incorrect response, an RT less than 200 ms or greater than 2000 ms, or from the first three trials of each block were discarded from RT analysis. Less than 0.5% of observations were excluded as a result of band-passing the RTs. The mean RT data were analyzed using a repeated measures analysis of variance (ANOVA) with three factors: congruency (same or different elevation), side (same or different cube), and proportion congruency (75 or 25% congruent). As displayed in Fig. 4, this analysis revealed a main effect of congruency [$F(1,13)=39.9, P<0.0001$], caused by faster RTs when tactile and visual stimuli were congruent (i.e. finger vibrations with upper LEDs, or thumb vibrations with lower LEDs) than incongruent (mean = 486 versus 537 ms). There was a main effect of side [$F(1,13)=38.3, P<0.0001$], with faster RTs when the two stimuli were on the same cube. These two factors entered into a significant interaction [$F(1,13)=31.5, P=0.0001$] with larger congruency effects when the visual distractor appeared on the same side as the tactile target (67 ms) versus different sides (35 ms). The factor of proportion congruent produced no main effects and did not interact with any other factor. Specifically, the three-way interaction did not approach significance [$F(1,13)<1.0$]. There is an apparent increase in the overall RT for the 25% condition; however, this was only marginally significant [$F(1,13)=3.5, P=0.08$]. Close inspection of Fig. 4 does suggest an overall larger effect of congruency for the high proportion congruent condition (58 ms) than for the low proportion congruent condition (44 ms), however, this difference does not approach significance [$F(1,13)=1.4, P=0.26$].

Analysis of the error data revealed a similar pattern (see Fig. 4). There was a main effect of congruency [$F(1,13)=12.4, P=0.004$], caused by more errors on incongruent trials (mean = 12.6%) than congruent trials (mean = 5.2%) overall. More errors were committed when the two stimuli were on the same cube (10.1%)

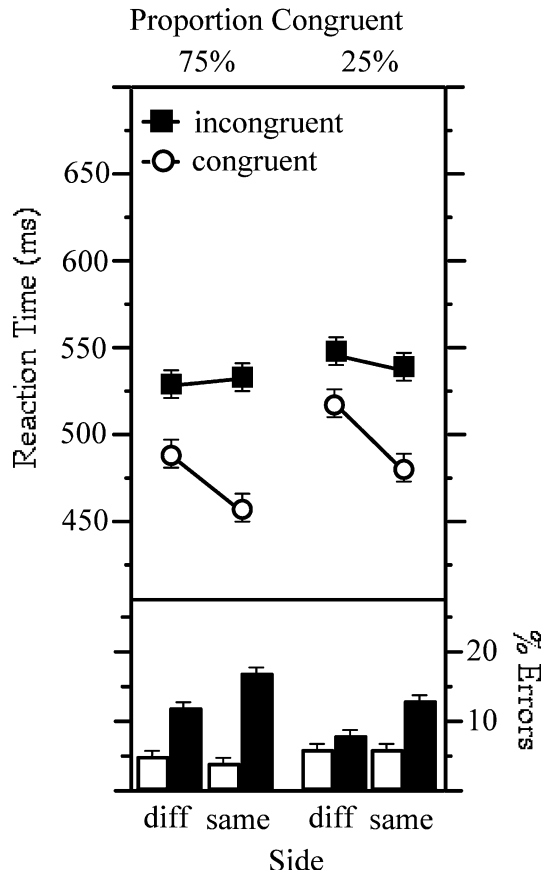


Fig. 4 Reaction time and error rate data from experiment 3. Proportion of congruent trials was either 75% (left panel) or 25% (right panel). The visual stimulus was presented 100 ms prior to the tactile stimulus compared to the previous experiments where this interval was 30 ms. Thus, the present data provide a direct comparison with Fig. 2. Black bars (errors) and squares (RT) represent data from the incongruent (different elevations) trials. White bars (errors) and circles (RTs) represent data from the congruent (same elevation) trials. Error bars represent the 95% confidence interval calculated from the within-observer MSe from the congruency by side interaction term of the ANOVA reported in the text (cf. Loftus and Masson 1994)

compared with when they were on different cubes (7.6%) [$F(1,13) = 10.8$, $P = 0.006$], resulting in a speed-accuracy trade-off across the cubes. That is, when the stimuli were on the same cube, observers were faster, but more error prone. This was not true for the interaction of congruency and side [$F(1,13) = 6.0$, $P = 0.03$], where the errors showed the same pattern as the RTs with a larger difference between same and different elevations when the stimuli were on the same cube (10.3%) compared with different cubes (4.5%).

Of most interest, the factor of proportion congruent entered into a single two-way interaction with congruency [$F(1,13) = 7.9$, $P = 0.01$]. There were more errors, regardless of side, for the high proportion congruent condition (9.4%) compared to the low proportion congruent condition (5.6%). This is the first evidence that top-down influence can be exerted in this task. The

three-way interaction between proportion congruent, congruency, and side was not significant [$F(1,13) < 1.0$].

Discussion

Increasing the lead-time for the visual event appears to have made a difference in the influence of the proportion congruency manipulation. There was a significant increase in the congruency effect, as indexed by error rate, for the high congruent condition compared to the low congruent condition. The same pattern was observed for the RTs, although this effect was not significant. It appears as though top-down control can influence this visuotactile task if given enough lead-time. Note, however, that this effect is independent of the spatial separation of the stimuli since the three-way interaction did not approach significance.

General discussion

In all three experiments, a robust visuotactile congruency effect was observed. The magnitude of this interference from an irrelevant visual distractor was not influenced by the proportion of congruent trials in experiments 1 and 2 where the proportion was varied from 75% congruent (experiment 1) to 11% congruent (experiment 2) demonstrating relative immunity of the task to top-down influence. In the final experiment, where the lead-time of the visual event was increased to 100 ms, there was a significant influence of proportion congruency, in terms of errors; a larger congruency effect was observed when there were a higher proportion of congruent trials. This is the pattern expected based on previous literature (Gratton et al. 1992; Logan and Zbrodoff 1979). This pattern was mirrored in the RTs but was not significant. It is important to note that the effect was the same regardless of whether the visual event was on the same side as the tactile stimulation.

The possible influence of top-down control in the visuotactile congruency task appears to be time-dependent. When the two stimuli were presented near simultaneously, integration was immune from top-down influences. With more time between the onset of the visual event and tactile event top-down control appears to have an influence. This is consistent with other data within the multisensory literature where both time and space are critically important to support integration of separate sensory systems (e.g. Stein and Meredith 1993). The relative effects of spatial and temporal manipulations on integration have been investigated using a temporal order judgment task (TOJ; Spence et al. 2001a; Zampini et al. 2003). In contrast to the present experiments, those studies examined the relative cost, in temporal precision, of having stimuli from different modalities at the same or different locations. Different locations produced better temporal precision. It was argued that when the stimuli appeared at the same

location, they were bound together producing a relative reduction in the ability to segregate them in time. In the present experiments, having the stimuli close together in time produced a stronger integration for stimuli presented at the same location. Future work needs to closely examine how time and space play off in controlling multisensory integration.

In terms of the source of the congruency effect, the present data argue strongly that it is not simply a matter of response conflict. Previous researchers examining the manipulation of proportion congruency have observed a strong effect on the size of the interference effect (e.g. Gratton et al. 1992; Lowe and Mitterer 1982; Posner and Snyder 1975; Shor 1975; Tzelgov et al. 1992) and this finding has been used to support the role of managing response conflict in these tasks. If one is willing to accept the strong version of the linking hypothesis between performance on the present task and operation of bimodal neurons in the human brain, then, when the visual and tactile events are presented at the same location, a single population of neurons responsive to this visuotactile receptive field is activated very strongly. When a visual event is presented to one digit and a tactile event to a different digit, two populations of neurons respond, one to each event. In terms of visuotactile neurons, the response to each stimulus may be very similar and in order to respond correctly the observer must discern which of the two responses was caused by the visual event. This may require a re-evaluation of the incoming sensory information that requires time and thus produces the congruency effect observed. If, on the other hand, the link between performance on the present task and operation of putative bimodal neurons in the human brain does not produce the observed findings, then one is forced to propose a third mechanism that both produces the interference effect and accounts for the lack of top-down influence in the task. Any such model would be less parsimonious than that proposed above assuming a strong form of the linking hypothesis.

Clearly, operation of these bimodal neurons cannot be assumed based on a single set of behavioural results, but rather, is supported by a number of converging findings. Critically, the present findings follow directly from the assumption of a link between the visuotactile congruency task and the operation of bimodal neurons in the human brain. In order to form more concrete conclusions regarding this link, neuroimaging techniques, such as EEG or MEG should be used. This is a difficult proposition since these tools tap system-level analysis and not the activation of single neurons, however, with the advent of new techniques and analysis tools, evidence in support of the link may be possible.

The fake hand effect

The relative role of response conflict versus sensory influences in the visuotactile congruency task was

recently investigated using the fake hand effect (Austin et al. 2004). The fake hand effect refers to the finding of significant congruency effects when the distracting lights are presented on a rubber hand (Pavani et al. 2000; Austen et al. 2004). The basic finding has been used to support a flexible body image/body schema (cf. Spence et al. 2004). That is, when the fake hand is placed in a biologically plausible posture, observers often mistake it for their own hand. This illusion can be augmented by synchronously stroking the fake and real hand (cf. Botvinick and Cohen 1998). Austin et al. (2004) examined the relative roles of response conflict and sensory factors by varying the relative mapping of stimulation to response—direct versus indirect. When direct, the observer indicated the stimulated digit by pressing on the vibrator itself, whereas with indirect mapping, the observer used a foot-pedal (as in the present experiments). While the overall reaction time was longer with the foot-pedal response, the size of the congruency effect did not vary. These authors argued for a sensory locus on the basis of these effects (Austin et al. 2004). While these results alone cannot force such a conclusion, they do lend support to the link, discussed above, between performance on this task and operation of bimodal neurons in the human brain and as such, are entirely consistent with the present findings.

Future directions

One issue that is highlighted by the present research is our lack of knowledge concerning the time-course of the visuotactile congruency task. The 30 ms SOA between the visual and tactile events was determined in “pilot testing” by Pavani et al. (2000) and has not been further explored (though see Spence et al. 2004). How will the interference from the visual event be modulated when this interval is increased or if the tactile event is presented prior to the visual event? While the 30 ms interval makes intuitive sense given our knowledge of early sensory processes (cf. Spence et al. 2001), it may be possible that a simultaneous presentation would produce equivalent findings given the tendency for the system to recalibrate for temporal intervals in this range (Bertelson et al. 2003). Future work should examine this variable parametrically in the visuotactile congruency task. It may be that the same “window of integration” seen in TOJ tasks will play a role in this task.

Conclusions

The visuotactile congruency task appears to be a good behavioural task to tap into the operation of relatively low-level neural processes (i.e. bimodal neurons in parietal and premotor cortices). The present findings support the link between performance in the task and the operation of relatively low-level neurons since they show a lack of top-down influence on visuotactile

integration tapped in this task, unless there is sufficient lead-time. Clearly, the effect of temporal asynchrony and stimulus intensity need to be more closely examined to be able to better characterize this task. In the same vein, the relation between this task and the standard attention-cuing paradigm needs to be explored to fully characterize the perceptual/cognitive system that is in operation.

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