# MULTISENSORY INTEGRATION BETWEEN VISUAL AND TACTILE MOTION INFORMATION: EVIDENCE FROM REDUNDANT-SIGNALS EFFECTS ON REACTION TIME

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## Abstract

*This study investigated the conditions under which visual and tactile motion information were integrated efficiently, employing redundancy gain paradigm (Miller, 1982). In the present experiments, visual motion stimuli and/or tactile motion stimuli were presented. Participants were asked to respond to stimuli of two sensory modalities as quickly as possible. It is well known that faster reaction times are observed for bimodal stimuli than for unimodal stimuli, and the facilitation is called redundancy gain. The present study manipulated figural configurations of visual motion stimuli, and examined whether the congruency of figural configurations between vision and touch would modulate the amount of redundancy gain and the reaction time distribution. The findings have important implications for the locus of multi-sensory integration between visual and tactile motion information.*

An increasing number of studies have shown multi-sensory interactions of motion information (Bensmaia et al., 2006; Craig, 2006; Meyer et al., 2005). Several studies have found the benefits from multimodal integration of motion information: motion signals for multiple sensory modalities facilitate detection of signals more than one modality. While much evidence for the integration of visual and auditory motion signals has been reported, considerably little is known about the integration of motion signals between vision and touch.

To contribute this unexplored issue, this study investigated whether motion perception benefits from the integration of visual and tactile signals. In order to establish an index of the integration, this study employed *redundancy gain paradigm* (Miller, 1982), which has been commonly used in a number of multi-sensory studies. In this paradigm, either the bimodal targets or the unimodal targets are randomly presented, and participants are asked to respond to the presentation of the target as quickly as possible. It has been known that the reaction times (RT) to bimodal signals are often faster than those to unimodal signals (redundant-signals effects). The facilitation, called *redundancy gain* (RG), has been assumed to be due either to the probabilistic summation of competitive signals (race model) or the multi-sensory integration of cooperative signals (co-activation model). Miller (1982) has developed a method, so-called distribution inequality test, to test between two separate models, in which the violation of the predicted distribution inequality by the race model is considered as a support of the co-activation model. Experiment 1, to confirm the existence of the redundant-signals effects for visual-tactile motion signals, presented visual and tactile motion stimuli, of which spatial locations, velocities and figural configurations were congruent. Furthermore, Experiments 2 and 3 were conducted to investigate the generality of the results shown in Experiment 1. Experiment 2 changed the figural configurations of visual stimuli used in Experiment 1 to examine whether the congruency of the figural configurations between visual and tactile motion stimuli is important for the integration. Experiment 3 presented static visual stimuli which had just the information of the direction of tactile motion stimuli to examine the need for a physical motion itself in the bimodal facilitation.

In addition, this study considered two nontrivial problems involved in the redundancy gain paradigm, and made some methodological manipulations for more conservative analysis. First, the random target sequences provide possible modality switches only at the unimodal trails. It has been shown that the RTs are slower when the target is preceded by the target for a different modality (Spence et al., 2001). Thus, the bimodal facilitation is possible to be due not to the bimodal processing gain, but to the modality switch costs at the unimodal trials (Gondan et al., 2004). To deal with this issue, the present study performed additional unimodal-only blocks in which only visual or tactile stimuli were presented through each block, and adopt this data as the unimodal RTs for analysis. Second issue is that the RG depends on the difference between two unimodal RTs. Previous studies demonstrated that the smaller the difference of RTs between two or more modality conditions was, the larger the RG was (Diederich & Colonius, 2004; Miller, 1986). Thus, it is possible that the reduction of RG is due to the large RT difference between modality conditions. To reduce the difference of RTs between two unimodal conditions, this study preliminarily measured the RT characteristics to visual stimuli for each participant, and manipulated the characteristics of visual stimuli used in following blocks.

## Method

### *Participants*

Ten (Experiment 1), twelve (Experiment 2), and ten (Experiment 3) undergraduate and graduate students at Tohoku University participated in the experiments. All had normal or corrected normal vision. The participants who participated in one experiment did not take part in any other experiments.

### *Apparatus and Stimuli*

A schematic view of the experimental apparatus is shown in Figure 1. The tactile stimuli were presented on participants' left forefinger pad through a vibro-tactile stimulator (Optacon II: Model R2B, Telesensory Systems Inc.), which was placed on the table in front of the participants. The tactile stimulus was a drifting line pattern consisted of a linear array of five activated tactors. The line pattern started to drift from the center of a forefinger pad in either the forward or backward direction at a velocity of 30.0 mm/sec (corresponded to visual angle 3.0 deg/sec).

Visual stimuli were presented on a 19-inch CRT monitor (CPD-G420, SONY) placed above the participant's head. Participants viewed the reflection of the visual stimuli on a mirror in front of them. The distance between the participant's head and the mirror was approximately 20 cm, and the distance between the mirror and their hands was about 30 cm. The mirror was semi-silvered (the transmission ratio was 30%), which allowed the participant's hands to remain visible together with the visual stimuli. The participant's head was stabilized by a chinrest to ensure that the visual and tactile stimuli were presented along the same horizontal plane. The visual stimuli used in each experiment were dynamic line patterns (Experiment 1), dynamic dots patterns (Experiment 2), and static arrow patterns (Experiment 3). Each stimulus was presented within a fixed rectangular box which had a width of 2.2 degrees and a height of 4.0 degrees. Except for Experiment 3, the visual stimuli drifted in either the forward or backward direction. The dynamic line pattern in Experiment 1 had a same velocity (3.0 deg/sec) and a same figural configuration as the tactile stimulus. The

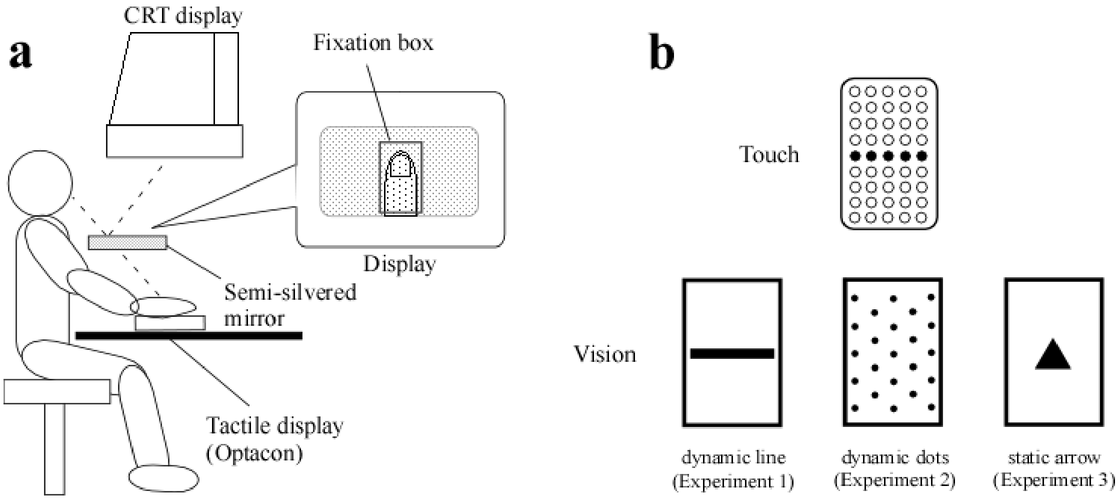


Fig. 1. Apparatus and stimuli. (a) The visual stimulus was generated on a CRT monitor placed above the participants' head and was projected onto a semi-silvered mirror. The tactile stimulus was generated by a visuo-tactile stimulator (Optacon) placed beneath the mirror. (b) A Schematic view of tactile and visual stimuli in each experiment. The visual stimuli in Experiments 1 and 2 drifted within the rectangular fixation box. In contrast, the visual stimuli in Experiment 3 were fixed at the center of the fixation box.

visual line pattern started to drift from the center of the fixation box, and the drifting locations appeared to be same as tactile line pattern. Experiment 2 employed the dynamic dot pattern which had same velocity as the tactile stimulus. Experiment 3 presented a static triangle-shape arrow pattern which had a side length of 0.7 degrees. The arrow pattern which pointed in either the forward or backward direction was presented at the center of the fixation box.

*Procedure*

Prior to the experiment, participants performed practice blocks for approximately 10 minutes until they became familiar with the stimuli and the task. Each trial began with the presentation of a visual fixation box, and 1000 ms later a bimodal (visual and tactile) or unimodal (visual or tactile) targets was presented. The drifting (or pointing) directions of visual and/or tactile targets were determined randomly for each trial. Participants were instructed to judge as quickly as possible if the target was moving or pointing either in the forward or upward direction using one of two corresponding keys with right hand. To nullify any auditory cues generated by the vibro-tactile stimulators, white noise was presented over headphones.

Each experiment had four different blocks: (a) preliminary visual-only, (b) tactile-only, (c) visual-only, and (d) bimodal block. The preliminary visual-only block was conducted to measure the individual RT characteristics for visual contrasts, and the results were used to determine the visual contrast in the subsequent visual-only block so as to reduce the difference of RTs between visual and tactile conditions. In the tactile-only and visual-only sessions, only tactile (T) and visual (V) targets were presented, respectively. In the bimodal block, which was exactly the same as conventional redundancy gain paradigm, either bimodal (V&T) or unimodal (visual or tactile) targets were presented. When bimodal targets were presented, two drifting (or pointing) directions were always consistent.

## Results and Discussion

First, in order to test for the presence of the redundant-signals effects, the RTs to bimodal targets (V&T) were compared with those to unimodal targets (V or T) (Table 1). For a very conservative analysis, the faster RT between V and T conditions for each participant was chosen as the unimodal RT. The RT data was analysed by means of a two-tailed t-test for matched pairs for each experiment. In Experiment 1, the bimodal RT ($M$ = 318.7 ms, $SD$ = 39.6) was significantly faster than the unimodal RT ($M$ = 327.6 ms, $SD$ = 35.1) [$t(9) = -2.33$, $p < .05$]. Similarly, Experiment 2 also had significantly faster RT of bimodal condition ($M$ = 338.5 ms, $SD$ = 35.7) than those of unimodal condition ($M$ = 354.0 ms, $SD$ = 40.18) [$t(11) = -2.23$, $p < .05$]. Meanwhile, Experiment 3 had no significant difference between bimodal conditions ($M$ = 322.6 ms, $SD$ = 48.7) and unimodal conditions ($M$ = 325.7 ms, $SD$ = 49.0) [$t(9) = -0.82$, $p = .43$].

Subsequently, cumulative distribution functions (CDFs) of RTs were calculated for bimodal and unimodal conditions for each participant to test the violations of race model inequality. Figure 2 shows the CDFs for bimodal and unimodal conditions for each experiment. The CDF for unimodal condition (V+T) was the sum of two CDFs of V and T conditions. For each experiment, the calculated CDFs were analysed by means of a one-tailed t-test at each of the 10 percentile points (5th, 15th, 25th and so on). In Experiment 1, CDF for bimodal condition was significantly faster than those for unimodal condition at 5th percentile [$t(9) = -6.89$, $p < .001$] and 15th percentile [$t(9) = -1.90$, $p < .05$]. Experiment 2 also had significant facilitations at 5th percentile [$t(11) = -2.70$, $p < .05$] and 15th percentile [$t(11) = -2.11$, $p < .05$]. In contrast, Experiment 3 had no significant facilitation at any percentile points.

The results of this study demonstrated that the redundant motion signals of vision and touch produced significantly faster detection for motion stimuli. Furthermore, the significant violation of the race model inequality provides a support that the facilitation is due to multi-sensory integration of motion signals. These results are consistent with the study which found the integration between visual and auditory motion signals (Meyer et al., 2005).
The facilitation seen in Experiment 1 was also confirmed in Experiment 2, in which the figural configurations of visual stimuli differed from those of tactile stimuli. In the previous studies which found the visual-auditory interactions (Meyer et al., 2005; Soto-Faraco et al., 2004), the figural configurations of visual and auditory stimuli could be considered to be incongruent because any auditory stimuli had no figural configurations. Taken together with the present findings, these results suggest that multi-sensory motion signals are robustly integrated whatever the configurations of motion stimuli are.

Unlike the results of Experiment 1 and 2, neither the RG nor the violation was confirmed in Experiment 3, although the static arrow pattern had the semantic information

Table 1. Mean RTs (ms) (SD in parentheses) for bimodal and unimodal conditions in each experiment.

| Modality | Visual Stimuli | | |
|---|---|---|---|
| | dynamic line (Ex. 1) | dynamic dots (Ex. 2) | static arrow (Ex. 3) |
| V&T | 319 (39.6) | 338 (35.7) | 323 (48.7) |
| V | 328 (34.5) | 356 (38.0) | 327 (48.8) |
| T | 355 (47.4) | 383 (38.8) | 350 (56.7) |

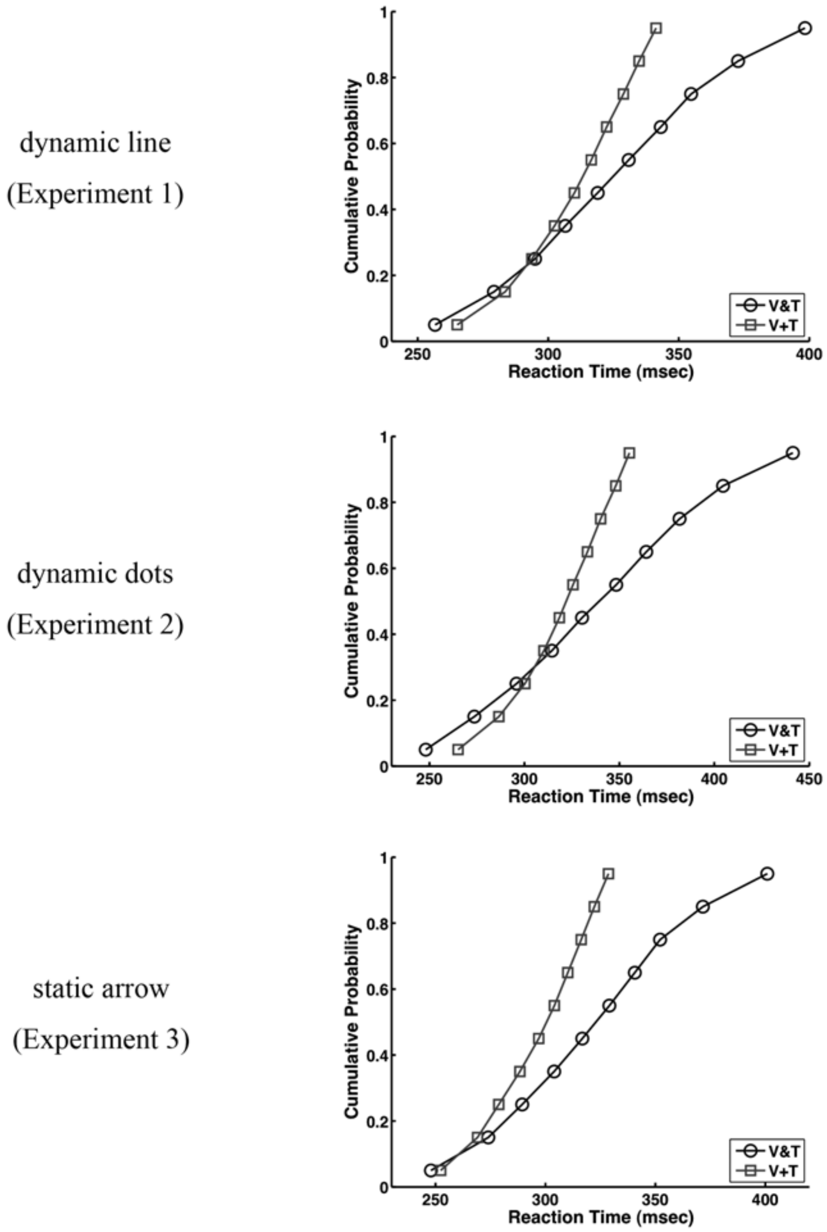


Figure 2. Cumulative distribution function (CDF) of RT in each experiment. Circles refer to the CDF for bimodal condition (V&T), and squares refer to the sum of two CDFs for unimodal conditions (V+T).

about motion direction. This result indicates that the multi-sensory facilitation of detection for motion direction is produced only when motion signals are presented on both modalities. Overall, these findings provide the implication that the motion signals of vision and touch are integrated in relatively low-level stages of perceptual processing.

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