

# Visual Motion Information Influences the Perceived Position of Touch

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This study investigated the influence of visual motion information on perceived tactile position. In Experiment 1, tactile stimuli were presented on participants' left and right index fingers together with visual motion stimuli projected onto a semi-silvered mirror, which allowed participants to view their hands. Participants were asked to discriminate the positional relationships of tactile stimuli. Discrimination performance differed depending on the relationship between the positions of the tactile stimuli and direction of the visual stimuli. In Experiment 2, a normal mirror was used which eliminated the view of the hands and the effects observed in Experiment 1 disappeared. These results suggest that the perceived spatial position of touch is displaced in the direction of visual motion, but this effect is dependent on vision of the stimulated body part.

**KEYWORDS:** cross-modal, tactile perception, visual motion, vision of body part

## 1. Introduction

Our external environment is ever changing. To respond to these changes, our brain processes sensory inputs from different modalities, and these inputs need to be dynamically integrated to form a unitary representation of external space.

Gray and Tan (2002) in their Experiment 2 examined the interaction between vision and touch and found faster discrimination speeds for vibration frequency of tactile stimuli when participants observed moving visual objects approaching the location of the tactile stimulation and the tactile stimulation is delivered at roughly the same point in time when visual objects would have arrived at that same spatial location of the tactile stimulation. Gray and Tan (2002) argued that due to dynamic cross-modal links in the spatial mapping between vision and touch, the sensory inputs from one sensory modality could be used to predict dynamic changes of stimulus position in another modality. However, Gray and Tan's results did not directly indicate the modulation of the perceived location of the tactile stimulus and hence, it is worth clarifying whether visual motion can induce perceptual changes in the location of tactile stimuli. Recent studies have shown that visual motion stimuli can capture the perceived direction of tactile motion stimuli (Craig, 2006) and influence the perceived speed of such stimuli (Bensmaia *et al.*, 2006). If these modulatory perceptual effects were based on a similar spatial cross-modal mapping system proposed by Gray and Tan (2002), it would be expected that perceptual changes in tactile position could also be induced by visual motion information.

To address this question, the present study investigated the influence of visual motion information on perceived tactile position. In Experiment 1, we examined whether perceived tactile position could be influenced by the direction of simultaneously presented visual motion stimuli. Tactile stimuli were presented bilaterally on the tip of the left and right index finger. The tactile stimuli were small enough to fit within the pad of the finger. Visual stimuli were presented on a mirror placed in front of the participants such that the visual stimuli appeared to be laid on the participants' fingers. The mirror used in Experiment 1 was semi-silvered to make the participants' hands visible. Participants were asked to discriminate the positional relationships of tactile stimuli presented on their left and right index fingers, while ignoring simultaneously presented visual motion stimuli. If the visual motion information affected the perceived tactile position, tactile position discriminations would be expected to be dependent on the direction of the visual motion stimuli.

Although the primary purpose of this study was to investigate the influence of visual motion information on perceived tactile position, a further goal was to determine whether or not a view of the body part receiving the tactile stimulation is important for visual-tactile interactions. There are previous reports that the sight of the body part influences visual-tactile interactions. For example, Tipper *et al.* (1998) reported that the sight of the stimulated body part enhanced simple reaction times for tactile stimuli. Similarly, Kennett *et al.* (2001) reported that viewing the body

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part decreased two-point discrimination thresholds. These results imply that visual information from a stimulated body part is integrated with tactile information. Therefore, in Experiment 2, the visual stimuli were presented in a normal mirror, which rendered the participants' own hand invisible, unlike in Experiment 1. If sight of the area receiving tactile stimulation is a crucial factor for the interaction between vision and touch, the absence of this view should reduce or eliminate the effects observed in Experiment 1.

## 2. Experiment 1

### 2.1 Method

#### 2.1.1 Participants

Fifteen right-handed undergraduate and graduate students at Tohoku University participated in the experiment. All had normal or corrected-to-normal vision and normal touch. No participants had previous experience with tactile displays.

#### 2.1.2 Apparatus and Materials

A schematic view of the experimental apparatus is shown in Fig. 1. The tactile stimuli consisted of line patterns were presented through vibro-tactile stimulators (Optacon II: Model R2B, Telesensory Systems Inc.). Two vibro-tactile stimulators were placed 16.0 cm apart (the center-to-center distance between two optacon displays along horizontal plane) on the table in front of the participants. One of the two tactile patterns was presented on participants' left forefinger pad, and the other on the right forefinger pad. The surface area of the tactile stimulator was 9.6 mm  $\times$  22.8 mm and it was consisted of 100 piezoelectric-driven vibrotactile tactors with five columns of twenty lines. The tactors were made to vibrate at 230 Hz. Each tactile line pattern consisted of a linear array of five activated tactors. As the position of the line pattern was randomly varied from trial to trial between the 5th and 15th lines of the tactile stimulator (with the first line referring to the nearest one from the fingertip), the vertical distance between two tactile patterns was termed as "relative distance" (Fig. 2). The minimum relative distance was 1.2 mm (corresponding to the distance of vertically adjacent tactors) and this was termed as "relative distance 1". We manipulated the relative distance between the line patterns in four steps from 1 to 4 (actual distance were 1 to 4  $\times$  1.2 mm).

Visual stimuli were presented using VSG 2/5 visual stimulus generator (Cambridge Research Systems) 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 consisted of two sinusoidal gratings drifting in either the forward or backward direction within bilaterally fixed windows positioned 1.8 degrees left and right of a central fixation cross. The spatial alignment of the visual stimuli corresponded to the locations of the participant's left and right forefingers. Each window had a width of 2.5 degrees and a height of 4.0 degrees. The gratings had a spatial frequency of 0.5 cpd, a contrast of 60%, and drifted at a velocity of 6.0 deg/sec.

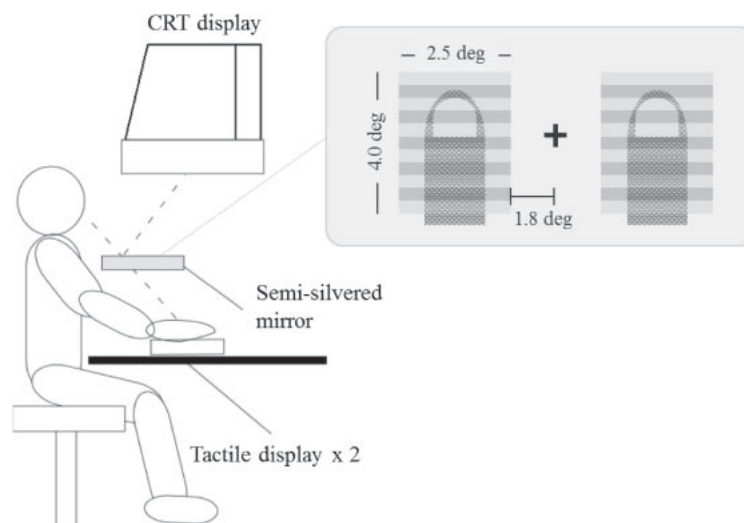


Fig. 1. A diagrammatic illustration of the experimental apparatus and stimuli. The visual stimulus was generated on a CRT monitor placed above the participant's head, and was projected onto a semi-silvered mirror (Experiment 1) or a normal mirror (Experiment 2). Participants' hands were positioned beneath the mirror, and could be seen in Experiment 1, but not in Experiment 2. The tactile stimulus was generated by two visuo-tactile stimulators (Optacon) placed bilaterally on the table.

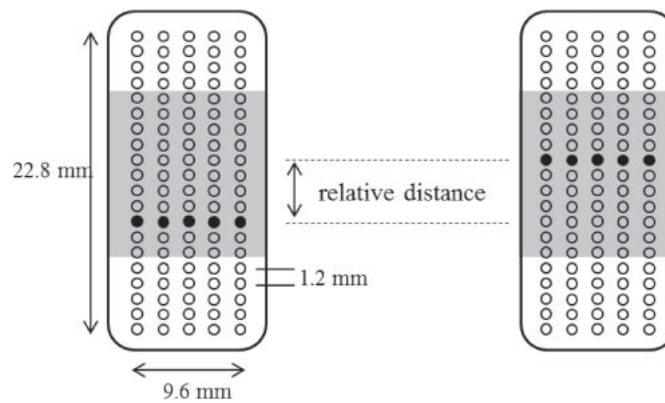


Fig. 2. A schematic view of tactile stimulus comprised of two line patterns (an example of a trial for which the relative distance of the tactile stimuli is set to 4). Each line pattern was a linear array of five activated factors. The distance between the left and right tactile patterns was defined as *relative distance*, with each unit placed 1.2 mm apart. The shaded area represents the possible locations where the line patterns would be presented.

### 2.1.3 Procedure

Prior to the experiment, participants performed practice blocks for approximately 20 minutes until they became familiar with the stimuli and the task. Each trial began with the presentation of a fixation cross, and 1000 ms later a visual stimulus was presented. A 100-ms tactile stimulus was presented 200 ms after the onset of the visual stimulus; and the visual stimulus continued during this time. The drifting direction of each visual grating and the position of each tactile pattern were determined randomly and independently for each trial. Participants completed a two alternative forced choice position discrimination task for the tactile stimulus. They were instructed to choose the side on which the tactile pattern appeared to be in a more forward position relative to themselves, while ignoring the simultaneously presented visual stimulus, and indicate their choice (left or right) using one of two corresponding foot pedals. To nullify any auditory cues generated by the vibro-tactile stimulators, white noise was presented over headphones.

As shown in Fig. 3, there were three different visual-tactile conditions, which were termed outward, inward, and same. In the outward and inward conditions, the left and right visual gratings drifted in the opposite direction. The difference between these two conditions was in the relationship between the direction of the visual stimuli and the positions of the tactile stimuli. In the outward condition, the directions of the two visual gratings were designed to expand the relative distance between the two tactile patterns, as for example, when the left tactile pattern was further forward than the right one, and the left visual grating drifted in a forward direction while the right grating drifted in a backward direction. Thus, the expected relationship between the visual and tactile stimuli was that the visual gratings would pull the two tactile patterns further apart. In contrast, for the inward condition the directions of the two visual gratings were designed to reduce the perceived relative distance of the two tactile patterns; this was the inverse of the outward condition. In the same condition, the two visual gratings drifted in the same direction, and this direction was randomly determined on each trial. Thus, the same condition was not expected to influence the perceived relative positions of the two tactile stimuli.

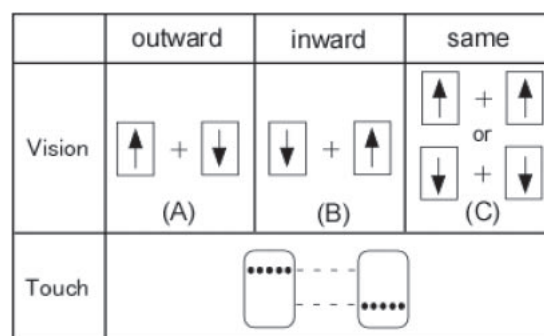


Fig. 3. An example of the visual-tactile condition in which the left tactile pattern was further forward than the right tactile pattern. (A) In the outward condition, the left visual grating drifted in forward direction and right grating in backward direction. (B) In the inward condition, the left visual grating drifted backward direction and the right grating drifted forward (the visual directions were inverse to the outward condition). (C) In the neutral condition, the two visual gratings drifted in same direction, either forward or backward.

In addition, tactile stimuli were also presented at zero relative distance; that is, the relative positions of the two tactile patterns were identical. There were three different zero relative distance conditions; left-forward, right-forward, and neutral. These conditions were similar to the visual-tactile conditions described previously, but had no relevance to tactile positions. In left-forward condition, the left-sided visual grating drifted in a forward direction, and right in a backward direction. The right-forward condition was simply the inverse of the left-forward condition. In the neutral condition, the two gratings drifted in the same direction, as determined randomly on each trial.

There were 64 trials in each visual-tactile condition at each relative distance (3 visual-tactile conditions  $\times$  4 relative distances  $\times$  64 trials), and 32 trials in each zero relative distance condition (3 zero relative distance conditions  $\times$  32 trials). Thus, each participant completed 864 trials in total, divided into eight blocks of 108 trials. Data from the visual tactile conditions was analyzed separately from the zero relative distance conditions.

## 2.2 Results and Discussion

For each participant, Weibull psychometric functions were fitted to the proportion of correct responses for each visual-tactile condition as a function of the relative distance between the left and right tactile patterns (Fig. 4), and a threshold was obtained. The threshold in this experiment represented the relative distance at which participants could discriminate the relative position of the two tactile patterns with 82% reliability.

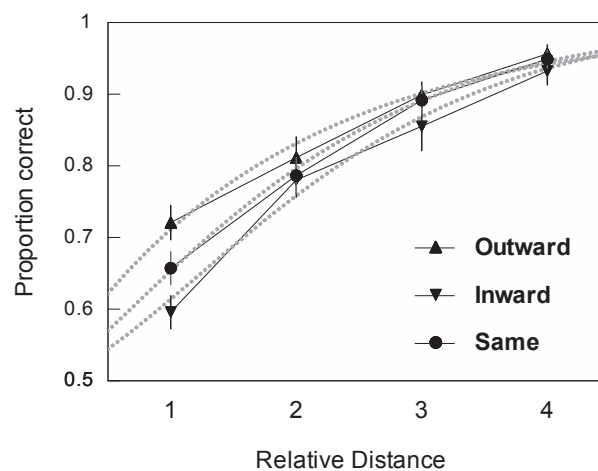


Fig. 4. Mean performance (proportion correct) in Experiment 1 as a function of the relative distance between the left and right tactile patterns, separately for visual-tactile conditions. Error bars correspond to the standard error in the mean. Data were modeled by a Weibull psychometric function.

The means (with standard deviations in parentheses) for the discrimination thresholds in the outward, inward, and same conditions were 2.27 (1.10), 2.87 (0.83), and 2.58 (0.89) mm, respectively. The threshold data was analyzed by means of a one-way analysis of variance (ANOVA), with the visual-tactile conditions as a within-participants factor. A significant main effect of visual-tactile condition was found [ $F(2, 28) = 3.55, p < .05$ ]. Pairwise comparisons (Ryan's procedure) showed that the average threshold of the outward condition was significantly smaller than that of the inward condition [ $t(28) = 2.66, p < .05$ ]. Although the average threshold for the neutral condition was larger than that for outward condition, and smaller than that for the inward condition, these differences were not significant. Taken together, these results demonstrate that the direction of the visual motion stimuli influenced position discrimination performance for static tactile stimuli. Furthermore, the results were consistent with the expected effects whereby the perceived position of the tactile stimuli was displaced in the direction of the visual motion stimuli. In the outward condition, if participants perceived the position of each of two tactile patterns to be shifted in the direction of visual motion stimuli, the two tactile patterns would be perceived to be more distant from each other. As a result, discrimination performance in the outward condition would be enhanced, because the apparent difficulty of the discriminations would be reduced. Meanwhile, in the inward condition, the tactile patterns could be perceived to be closer, thereby resulting in an increase in the apparent difficulty level of discriminations and a decrease in performance.

Further evidence of a visual-tactile interaction was sought from the data obtained in the zero relative distance conditions, where there was no difference in the relative position of the tactile patterns between the left and right hands. For each visual direction condition at zero relative distance, the proportion of responses indicating that the right tactile pattern appeared to be further forward than the left was entered into the analysis. The means (with standard deviations in parentheses) for the proportion(%) in left-forward, right-forward, and control condition were 60.8 (15.3), 49.8 (14.8), and 55.0 (13.9), respectively. A one-way ANOVA with visual direction as a within-participants factor showed a

significant main effect of visual direction [ $F(2, 28) = 3.41, p < .05$ ]. Post hoc pairwise comparisons showed that the proportion of responses indicating the right stimulus was more forward was significantly greater in the right-forward condition than in left-forward condition [ $t(28) = 2.61, p < .05$ ]. No significant differences were found between the left-forward and neutral conditions, or between the right-forward and neutral conditions. This result further supports the idea that tactile stimuli were perceived to shift in the same direction as the drifting visual stimuli.

Overall, these results demonstrated that a change in perceived tactile position occurred when visual motion information was simultaneously presented. However, the possibility remains that the enhanced tactile position discrimination performance in the outward condition relative to the inward condition might not have been due to a perceptual modulation of tactile position, but instead to a response bias in which participants simply chose the side on which the visual grating was drifting in a forward direction. This type of response bias would result in an increase in the proportion of correct responses in the outward condition, and a decrease in the inward condition. As well, it is possible that the modulatory effect observed across the zero relative distance conditions represented a similar response bias. Because this possibility could not be excluded based on Experiment 1, this issue is discussed in terms of the results of Experiment 2.

### 3. Experiment 2

#### 3.1 Method

##### 3.1.1 Participants

Fifteen right-handed undergraduate and graduate students at Tohoku University participated in this experiment. Six of them had taken part in the first experiment. All had normal or corrected-to-normal vision and normal touch.

##### 3.1.2 Apparatus and Materials

In Experiment 2, the mirror used in Experiment 1 was changed to a normal non-transmissive mirror which eliminated vision of the hand during the experiment. All other materials and procedural details were identical to those of Experiment 1.

#### 3.2 Results and Discussion

The data was analyzed in the same manner as in Experiment 1. Fig. 5 shows the results of Experiment 2. The means (with standard deviations in parentheses) for the thresholds in outward, inward, and same conditions were 2.53 (1.58), 2.21 (1.01), 2.45 (1.05) mm, respectively. No significant main effect of visual-tactile condition was seen for the threshold discrimination data [ $F(2, 28) = 0.33, p = 0.72$ ]. Similarly, analysis of the no relative distance data showed no significant main effect of zero relative distance condition [ $F(2, 28) = 0.761, p = 0.48$ ]. Indeed, the mean proportions were quite similar across the left-forward (50.6%,  $SD = 19.5$ ), right-forward (54.6%,  $SD = 19.5$ ), and control condition (55.6%,  $SD = 15.7$ ). Thus, the modulatory effect observed in Experiment 1 disappeared when vision of the hands was eliminated. These findings were consistent with previous studies that have shown that vision of the stimulated body part enhances tactile discrimination performance (Kennett, 2001; Tipper, 1998).

The results of Experiment 2 allow for clarification as to whether the effects observed in Experiment 1 were attributable to perceptual modulation or a response bias. If the effects observed in Experiment 1 resulted from a

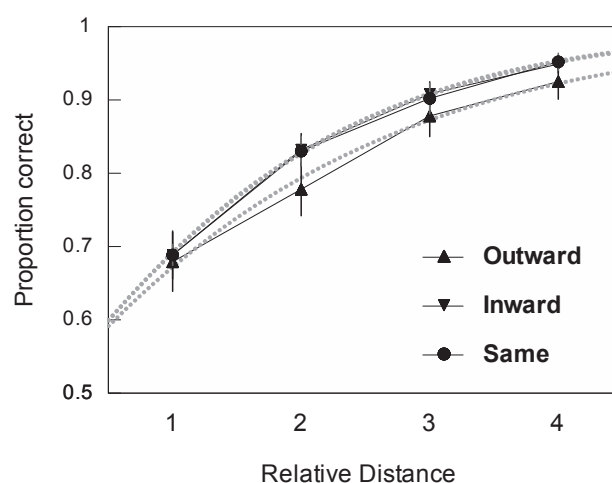


Fig. 5. Mean performance (proportion correct) in Experiment 2 as a function of the relative distance between the left and right tactile patterns, separately for visual-tactile conditions. Error bars correspond to the standard error in the mean. Data were modeled by a Weibull psychometric function.

response bias, similar effects should have also emerged in Experiment 2; the only methodological difference between the two experiments was the manipulation of sight of the stimulated body part. It is unlikely that a response bias would be affected by the sight of the stimulated body part. Therefore, the effects observed in Experiment 1 are most likely due to changes in the perceived spatial position of the tactile stimuli, rather than a simple response bias.

#### 4. General Discussion

The present study investigated whether visual motion information could influence perceived tactile position, and whether the presence or absence of sight of the stimulated body part would influence such a cross-modal interaction. The results demonstrated that position discrimination thresholds for tactile stimuli delivered bilaterally to the fingertips were significantly influenced by the direction of motion in spatially corresponding visual stimuli. However, the effects of the visual stimuli emerged only when participants were able to view their hands together with the visual stimuli.

In Experiment 1, discrimination thresholds for the relative position of two staggered tactile patterns were reduced when two visual gratings moving in opposite directions were presented such that the direction of motion would separate the two tactile patterns, as compared to the reverse situation in which the visual stimuli would induce the tactile patterns to move together. Additionally, when the two tactile patterns were presented in the same position, the tactile pattern on the side where the visual stimuli drifted in a forward direction was more often rated as in a forward position as compared to the side on which the visual motion direction moved backwards. Both of these results are consistent with the idea that the perceived position of tactile stimuli can be displaced in the direction of visual motion.

Consistent with previous research examining visual-tactile interactions (Bensmaia *et al.*, 2006; Craig, 2006; Gray and Tan 2002; Spence *et al.*, 1998), Experiment 1 showed that irrelevant visual information influenced tactile perception. In terms of the influence of visual motion information on tactile perception, Craig (2006) reported that the perceived direction of tactile motion stimuli was modulated by the direction of visual motion stimuli, and Bensmaia *et al.* (2006) reported that the perceived velocity of tactile motion was modulated by visual motion. They argued that this visual-tactile interaction seen for dynamic stimuli occurred during perceptual processing rather than during post-perceptual processing, and this effect did not represent a response bias. Considered together, the results of Experiments 1 and 2 demonstrate that the effects seen in Experiment 1 were due to a perceived change in stimulated tactile position rather than to the results of participants' response bias.

It is possible that dynamic cross-modal links, as put forward by Gray and Tan (2002), underlie the perceptual shift in tactile position induced by the visual motion signal in the present study. This type of predictive updating in spatial mapping has also been discussed in studies of visual perception. It has been shown that a motion after-effect can result not only from perceived movement of a static pattern, but also from a shift in its perceived position (Nishida & Johnston, 1999; Snowden, 1998). These findings suggest that there is a predictive mechanism in spatial mapping which estimates the future position of the stimulus, be it actually motion or illusory motion. The results of Experiment 1 and those of Gray and Tan may be related to the same mechanisms underlying the shifts in perceived visual motion.

The effects seen in Experiment 1 when participants observed their hands were not seen in Experiment 2 when vision of the hands was eliminated. Several behavioral studies have found that allowing a view of the body influenced the interaction between vision and touch (Kennett *et al.*, 2001; Pavani *et al.*, 2000; Tipper *et al.*, 1998). Indeed, Kennett *et al.* (2001) found that even a view of a non-informative body sight decreased participants' two-point discrimination thresholds, and a magnified view of a body sight further decreased the threshold. Thus, the spatial resolution of vision appears to influence the spatial resolution of touch. These results indicate that allowing the sight of a body part plays an important role in cross-modal links between vision and touch. Thus, the removal of this view in Experiment 2 might well have eliminated or weakened the cross-modal links between vision and touch, and abolished any modulatory effect of vision on position discrimination.

The behavioral results from the present study are supported by the multi-modal neural mechanisms demonstrated in several previous neuro-physiological studies on monkeys (Duhamel *et al.*, 1997; Graziano & Gross, 1993; Graziano *et al.*, 1997; Hu *et al.*, 1998). It has been reported that there are bimodal cells in the primate brain which are responsive to tactile and visual stimuli. For these bimodal cells, the visual receptive field is located near the tactile receptive field; for example, a spatial area near the hand or face. Interestingly, visual receptive fields near the hands moved with the hands, and when the hands were out of view (e.g., behind the monkey) the cells no longer responded to any visual stimuli (Graziano & Gross, 1993). It is possible that bimodal cells like these are involved in the integration of visual and tactile inputs in humans, and eliminating the view of the hands in Experiment 2 eliminated this integration.

In summary, the present study demonstrated that the perceived position of tactile stimuli depended on the direction of simultaneously presented visual motion stimuli. However, additional work is needed to confirm whether visual motion information actually displaces the perceived position of tactile stimuli. If the perceived position of the tactile stimuli shifts with the future position of visual stimuli, the magnitude of the tactile positional shift should depend on the velocity of the visual stimuli. Such investigations would allow for a determination as to whether the effects observed are due to perceptual processes or post-perceptual processes.

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