CROSS-MODAL INFLUENCES ON REPRESENTATIONAL MOMENTUM AND REPRESENTATIONAL GRAVITY

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Abstract

Effects of cross-modal information on representational momentum and on representational gravity were examined. In Experiment 1, ascending or descending visual motion (changing location) was paired with ascending or descending auditory motion (changing frequency); motion was congruent (both ascending, both descending) or incongruent (one ascending, one descending). Memory for visual location or auditory pitch was probed. Congruency resulted in larger forward displacement for auditory pitch, but did not influence forward displacement for visual location. In Experiment 2, leftward or rightward visual motion was paired with ascending, descending, or no auditory motion. Memory for visual location was displaced downward with descending or no auditory motion, and downward displacement was larger for visual motion paired with descending auditory motion than for visual motion paired with ascending auditory motion. Effects of cross-modal information on displacement suggest representational momentum and representational gravity reflect high-level processing.

Memory for the final location of a target is often displaced in the direction of target motion, and this displacement has been referred to as *representational momentum* (RM) and attributed to mechanisms ranging from low-level perceptual processes to high-level cognitive processes (Hubbard, in press). Although RM has been reported with auditory targets (e.g., Johnston & Jones, 2006) and with haptic targets (e.g., Brouwer et al., 2004), the majority of research on RM involves visual targets (for review, Hubbard, 2005). RM for a visual target is influenced by other visual stimuli (e.g., Hubbard & Ruppel, 1999), but whether RM for visual targets is influenced by auditory stimuli, or whether RM for auditory targets is influenced by visual stimuli, has not been examined.

Hubbard (2005, 2006) concluded that the existence of RM in visual, auditory, and haptic modalities reflected a single high-level process or small number of high-level processes rather than numerous modality-specific or dimension-specific low-level processes. Kerzel (2006) challenged this notion and concluded RM resulted from numerous low-level and modality-specific processes. One way to resolve this issue is to examine whether visual information and auditory information interact in the displacement of multimodal targets. Influences of visual information on auditory displacement, or influences of auditory information on visual displacement, would suggest high-level processes rather than low-level or modality-specific processes are at least partly responsible for displacement.

Experiment 1

Participants were presented with a multimodal target on each trial. Each target consisted of five sequentially presented inducing stimuli, and each inducing stimulus consisted of a visual component and an auditory component. Visual motion and auditory motion of each target were congruent (i.e., visual motion ascended and auditory motion ascended, visual motion descended and auditory motion descended) or incongruent (i.e., visual motion ascended and auditory motion descended, visual motion descended and auditory motion ascended). In one block of trials, memory for final visual location was probed, and in another block of trials, memory for final auditory pitch was probed. If RM reflects high-level processes, then displacement in the probed modality should be influenced by whether motion in the unprobed modality is congruent or incongruent with motion in the probed modality.

Method

Participants. The participants were 22 undergraduates who received partial course credit and were naive to the hypotheses.

Apparatus. The stimuli were generated by and the data collected by an Apple iMac desktop computer equipped with a 15-inch color monitor.

Stimuli. The visual component of each target was a black square 20 pixels (0.83 degrees) wide on a white background. For ascending visual motion, the first inducing stimulus appeared midway between the bottom and center of the display, and each successive inducing stimulus was 40 pixels (1.66 degrees) above the previous inducing stimulus; for descending visual motion, the first inducing stimulus appeared midway between the top and center of the display, and each successive inducing stimulus was 40 pixels below the previous inducing stimulus. The auditory component of each target was a tone. For ascending auditory motion, the first inducing stimulus was a tone of 60 Hz, and each successive inducing stimulus increased in pitch by one octave (i.e., 60, 120, 240, 480, 960 Hz); for descending auditory motion, the first inducing stimulus was a tone of 960 Hz, and each successive inducing stimulus decreased in pitch by one octave (i.e., 960, 480, 240, 120, 60 Hz). Each inducing stimulus was presented for 250 milliseconds, and the ISI between successive inducing stimuli and between the final inducing stimulus and the probe was 250 milliseconds.

The visual probe was the same size and shape as the visual inducing stimuli, located at the same horizontal coordinates as the final inducing stimulus, and located at one of nine vertical locations relative to the final inducing stimulus: -12, -9, -6, -3, 0, +3, +6, +9, or +12 pixels. The auditory probe was one of nine frequencies relative to the final inducing stimulus: -100, -75, -50, -25, 0, +25, +50, +75, or +100 cents (1 cent = 1/100 semitone). For visual probes and auditory probes, probes with a minus sign were backward (i.e., shifted in the direction opposite to target motion), probes with a plus sign were forward (i.e., shifted in the direction of target motion), and zero unsigned probes were at the same location or frequency as the final inducing stimulus.

Design. Each participant completed two blocks of trials. Targets were the same in each block; one block presented visual probes (i.e., measured visual displacement), and the second block presented auditory probes (i.e., measured auditory displacement). Each block consisted of 216 trials (2 congruencies [congruent, incongruent] x 9 probe positions [-12, -9, -6, -3, 0, +3, +6, +9, +12 in the visual probe block; -100, -75, -50, -25, 0, +25, +50, +75, +100 in the auditory probe block] x 2 directions [ascending, descending] x 6 replications) in a different random order. Order of blocks was counterbalanced across participants.

Procedure. In each block, participants were given 10 practice trials randomly drawn from experimental trials in that block. Participants initiated each trial by pressing a designated key. There was a one second pause, and then the first inducing stimulus appeared. After the final inducing stimulus disappeared, a visual probe or an auditory probe was presented. Participants pressed a key marked *S* or a key marked *D* to indicate whether the probe was the same as the final inducing stimulus. Participants then pressed a key marked with an upward arrow or a key marked with a downward arrow to indicate whether motion in the other (unprobed) modality was ascending or descending. Participants then initiated the next trial.

Results

Probabilities of a *same* response for each probe position for congruent trials and for incongruent trials are shown in Figure 1. Estimates of displacement were determined by calculating the weighted mean (WM; the sum of the products of the proportion of *same* responses and the distance of the probe from the final location of the moving target, in pixels [visual probes] or cents [auditory probes], divided by the sum of the proportions of *same* responses) for each participant for each condition. The sign of a WM indicated the direction of displacement (i.e., a minus sign indicated backward displacement, a plus sign indicated forward displacement), and the absolute value of a WM indicated the magnitude of displacement (i.e., a larger absolute value indicated larger displacement). A WM larger than zero indicated RM occurred.

Visual Probes. WMs for visual probes were analyzed in a 2 (congruency) x 2 (visual direction) repeated measures ANOVA. Visual forward displacement was not influenced by whether auditory motion was congruent (M = 2.11) or incongruent (M = 2.19), F(1, 20) = 0.30, $p > .62$, nor did Congruency interact with Direction, F(1,20) = 0.35, $p > .56$. Forward displacement was larger for descending visual motion (M = 2.80) than for ascending visual motion (M = 1.50), F(1,20) = 8.41, $p > .009$. WMs for congruent trials, t(21) = 7.62, $p < .0001$, and incongruent trials, t(21) = 6.79, $p < .0001$, were larger than zero. Participants reported the correct direction of auditory motion on 98% of trials.

Auditory Probes. WMs for auditory probes were analyzed in a 2 (congruency) x 2 (auditory direction) repeated measures ANOVA. Auditory forward displacement was larger when visual motion was congruent (M = 2.95) than when visual motion was incongruent (M = -0.06), F(1, 20) = 9.18, $p < .007$. Forward displacement was larger for descending auditory motion (M = 4.78) than for ascending auditory motion (M = -1.90), F(1,20) = 4.80, $p < .05$. Congruency x Direction did not approach significance, F(1,20) = 0.70, $p > .41$. WMs for congruent trials were larger than zero, t(21) = 2.26, $p < .04$, but WMs for incongruent trials did not differ from zero, t(21) = -0.050, $p > .95$. Participants reported the correct direction of visual motion on 100% of trials.

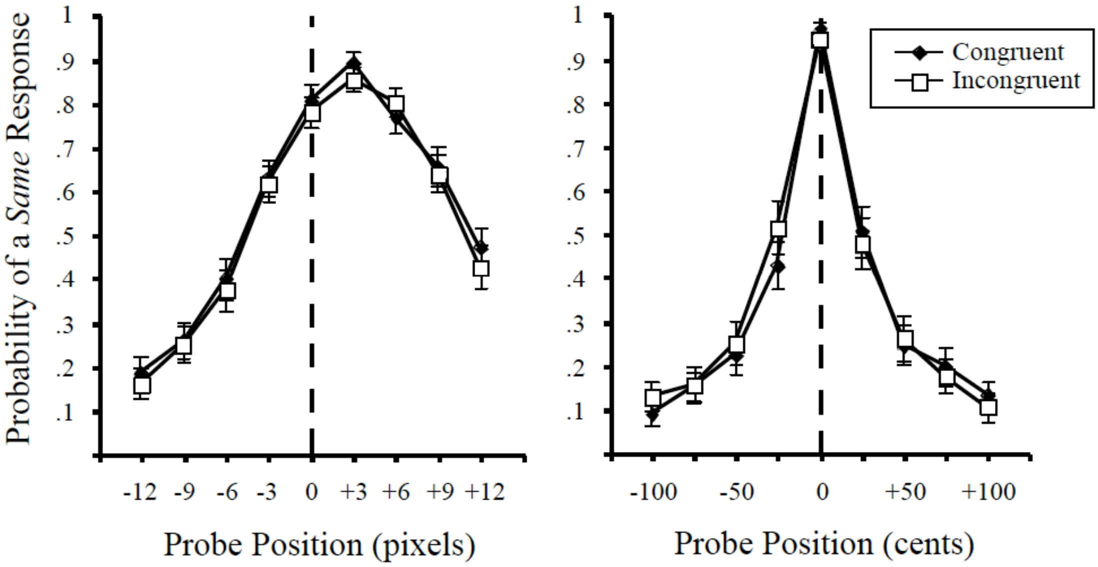

Figure 1. Probability of a *same* response as a function of probe position for visual probes (left) and auditory probes (right) in Experiment 1.

Discussion

Forward displacement of visual location was not influenced by whether auditory motion was congruent or incongruent with visual motion. Forward displacement of auditory pitch occurred when visual motion was congruent with auditory motion but not when visual motion was incongruent with auditory motion. In auditory displacement, when visual motion and auditory motion were congruent, the two components summed, and forward displacement was larger, but when visual motion and auditory motion were incongruent, the two components partially canceled, and forward displacement was smaller. Influence of visual motion on auditory RM, coupled with a lack of influence of auditory motion on visual RM, is consistent with visual dominance in perception (e.g., Posner et al., 1976).

Experiment 2

If failure of auditory motion to influence visual displacement in Experiment 1 was due to visual dominance, then an influence of auditory motion on visual displacement might be found if auditory information could be made relatively stronger. Memory for the final location of a horizontally moving visual target is displaced downward in the direction consistent with implied gravitational attraction, and this has been referred to as *representational gravity* (RG; Hubbard, 1995, 1997). The magnitude of downward displacement is considerably less than the magnitude of forward displacement in such targets (Hubbard, 1990), and so it is possible a relatively stronger RM for ascending or descending auditory motion might influence a relatively weaker RG for horizontal visual motion. In Experiment 2, the visual component of the target was a square that moved leftward or rightward, and the auditory component of the target was a tone that ascended or descended in frequency.

Method

Participants. The participants were 22 undergraduates who received partial course credit and were naive to the hypotheses, and none had participated in Experiment 1.

Apparatus. The apparatus was the same as in Experiment 1.

Stimuli. The visual component of the target was the same as in Experiment 1, with the following exceptions: Targets moved leftward or rightward rather than ascending or descending. For leftward motion, the first inducing stimulus appeared midway between the right side and center of the display, and each successive inducing stimulus was 40 pixels left of the previous inducing stimulus; for rightward motion, the first inducing stimulus appeared midway between the left side and center of the display, and each successive inducing stimulus was 40 pixels right of the previous inducing stimulus. Inducing stimuli were centered along the vertical axis. The probe was located at the same horizontal coordinates as the final inducing stimulus and at one of nine vertical positions relative to the final inducing stimulus: -8, -6, -4, -2, 0, +2, +4, +6, or +8 pixels. Probes with a minus sign or a plus sign were below or above, respectively, the location of the target, and zero unsigned probes were at the same location as the target. The auditory component of the target was the same as in Experiment 1, except a condition in which no auditory stimulus was presented was also included.

Design. Each participant completed one block consisting of 216 trials (3 auditory motion [ascending, descending, none] x 9 probe positions [-8, -6, -4, -2, 0, +2, +4, +6, +8] x 2 visual directions [leftward, rightward] x 4 replications) presented in a different random order.

Procedure. The procedure was the same as in the visual probe block in Experiment 1, but participants did not indicate auditory direction when auditory motion was not presented.

Results

Probabilities of a *same* response for each probe position for ascending, descending, and no auditory motion are shown in Figure 2, and WM estimates of displacement were calculated as in Experiment 1. WMs were analyzed in a 3 (auditory direction) x 2 (visual direction) repeated measures ANOVA. Visual displacement was influenced by whether auditory motion ascended (M = -0.18), descended (M = -0.625), or was not present (M = -0.53), $F(2, 42) = 3.27$, $p < .05$; least mean square comparisons suggested visual downward displacement when auditory motion descended was larger than when auditory motion ascended, and that visual downward displacement when no auditory motion was presented was marginally larger ($p < .07$) than when auditory motion ascended. Neither visual direction, $F(1,21) = 0.02$, $p > .89$, nor Visual Direction x Auditory Direction, $F(2,42) = 0.83$, $p > .44$, were significant. WMs when auditory motion descended, $t(21) = -2.93$, $p < .01$, and when no auditory motion was presented, $t(21) = -2.75$, $p < .02$, were less than zero, but WMs when auditory motion ascended did not differ from zero, $t(21) = -0.71$, $p > .48$. When auditory motion was presented, participants reported the correct direction of auditory motion on 98% of trials.

Discussion

Downward displacement for visual horizontal motion was influenced by auditory motion. When auditory motion descended, visual downward displacement was larger than when auditory motion ascended. Visual RG occurred when auditory motion was in the direction consistent with gravitational attraction or when no auditory motion was presented, but visual RG did not occur when auditory motion was in the direction opposite to gravitational attraction. Downward displacement for visual motion when auditory motion was present reflects a combination of visual information and auditory information. When RG of visual motion and RM of auditory motion were congruent (descending auditory motion), they summed, and visual downward displacement was larger; when RG of visual motion and RM of auditory motion were incongruent (ascending auditory motion), they partially canceled, and visual downward displacement was smaller.

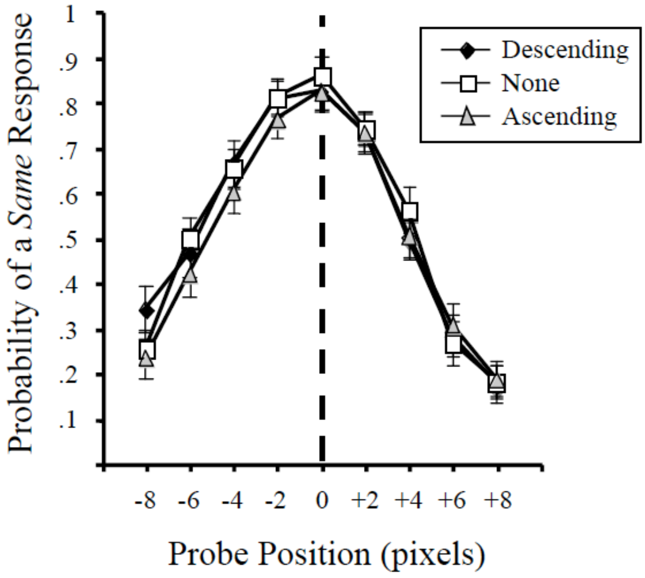

Figure 2. Probability of a *same* response as a function of probe position in Experiment 2.

General Discussion

Experiments 1 and 2 examined whether (a) auditory motion could influence visual RM, (b) visual motion could influence auditory RM, and (c) auditory motion could influence visual RG. Cross-modal influences in Experiments 1 and 2 of visual motion on auditory RM and of auditory motion on visual RG are not consistent with the notion RM and RG result from low-level processes; information from vision and information from audition are more likely to combine in high-level processes rather than in low-level or modality-specific processes.

Results of Experiment 1 are consistent with perceptual visual dominance. Results of Experiment 2 suggest auditory information influences visual displacement if auditory information is stronger than visual information, and this is consistent with findings that visual dominance in perception is diminished when auditory information is stronger (e.g., Sinnett et al., 2007). Interestingly, visual RG and auditory RM combined to determine visual downward displacement even though RG and RM are statistically independent (cf. Motes et al., 2008). Visual dominance in RM is consistent with continuity in representation from perception to memory in which (bottom-up) properties of perception influence memory and (top-down) properties of memory influence perception. Influences of visual motion on auditory displacement, and influences of auditory motion on visual displacement, are consistent with ample evidence that top-down information and high-level processes influence displacement. Such cross-modal influences also underscore that the ultimate displacement of a target is multiply-determined.

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