AUDITORY MOTION AND VISUAL REPRESENTATIONAL MOMENTUM: EFFECTS OF RESPONSE METHOD

Nuno A. De Sá Teixeira[1] & Timothy L. Hubbard[2]
[1]*Institute of Cognitive Psychology, University of Coimbra*
nuno_desateixeira@fpce.uc.pt
[2]*Department of Psychology, Texas Christian University*
timothyleehubbard@gmail.com

Abstract

Whether representational momentum results primarily from low-level mechanisms or from high-level mechanisms, and whether representational momentum for a stimulus in one modality is influenced by a stimulus in another modality, have been debated. These issues were examined in two experiments. A smoothly moving visual stimulus that ascended or descended in the picture plane was paired with a smoothly moving auditory stimulus that ascended or descended in frequency space, and visual motion and auditory motion were congruent (both ascending or both descending) or incongruent (one ascending and one descending). Representational momentum for the visual stimulus was measured by a motor localization task (cursor positioning, Experiment 1) or an identification task (probe judgment, Experiment 2). A main effect of congruency did not occur. An interaction between congruency and visual movement direction occurred in identification but not in localization. An account involving differences between visual pathways for action and for identification is suggested.

A moving target is usually remembered as having traveled slightly further than it actually traveled (e.g., the remembered final location is displaced slightly forward in the direction of motion from the actual final location), and this displacement is referred to as *representational momentum* (RM; Freyd & Finke, 1984). The remembered final location of a horizontally moving target is also displaced slightly downward from the actual final location, and this is referred to as *representational gravity* (RG; Hubbard, 1997). Much has been learned about RM and RG (for review, Hubbard, 2005), but questions remain. One question is whether RM and RG result from low-level perceptual mechanisms or high-order cognitive mechanisms (for review, Hubbard, 2010), and a second question is whether RM and RG in one modality can be influenced by information presented in another modality. The experiments reported here address these questions by measuring RM for a moving visual target when concurrent auditory motion is in the same or opposite direction as motion of the visual target.

In the only published example of cross-modal influences on RM and RG, Hubbard and Courtney (2010) presented visual targets that ascended or descended in the picture plane paired with auditory targets that ascended or descended in frequency space (i.e., in auditory pitch). If RM resulted from low-level and modality-specific mechanisms, then direction of auditory motion should not influence visual RM and direction of visual motion should not influence auditory RM. In Experiment 1, motion on each trial was congruent (visual motion ascended and auditory motion ascended, visual motion descended and auditory motion descended) or incongruent (visual motion ascended and auditory motion descended, visual motion descended and auditory motion ascended). Visual RM was not influenced by whether auditory motion was congruent or incongruent, but auditory RM was larger if visual motion was congruent than if visual motion was incongruent. In Experiment 2, visual motion was leftward or rightward, and auditory motion was ascending or descending. Visual RG was larger if auditory motion was descending than if auditory motion was ascending.

Hubbard and Courtney presented implied motion of visual targets and auditory targets, and estimates of RM and RG were based on judgments of visual probes or auditory probes presented after targets vanished. Methods of stimulus presentation and of response collection influence estimates of RM (Ashida, 2004; Kerzel, 2003), and so it is possible the lack of effect of auditory motion on visual RM in Hubbard and Courtney was related to the method of stimulus presentation or of response collection. The experiments reported here examine influences of auditory motion on visual RM by presenting smooth motion targets and either a cursor-positioning or probe judgment response; an influence of auditory motion on visual RM would be consistent with a high-level mechanism for RM and with Hubbard and Courtney's findings of effects of visual motion on auditory RM and auditory motion on visual RG.

Experiment 1

Participants were presented with ascending or descending smooth visual motion in the picture plane paired with ascending or descending smooth auditory motion in frequency space. On half of the trials, visual motion and auditory motion were congruent, and on half of the trials visual motion and auditory motion were incongruent. After the target vanished, participants indicated the final location of the visual target by using the mouse to position the cursor at the judged final location and clicking a button on the mouse.

Method

Participants. Participants were 21 individuals associated with the University of Coimbra (16 female and 5 male, mean age of 26.38 years). All were naive regarding the hypotheses and reported normal or corrected-to-normal vision and hearing.

Apparatus. Stimuli were presented and responses collected using Super Lab 4.0 on a Sony Vaio (VGN-FZ31M) computer connected to an external monitor with 1280×800 pixels of resolution and equipped with a wireless mouse.

Stimuli. The stimulus on each trial was composed of a visual target and an auditory target. The visual target was a black square 35 pixels (1.11 degrees of visual angle) on each side and was presented on a white background. The visual target appeared in the center of the display and exhibited smooth motion at a constant velocity of 112 pixels (3.5 degrees) per second. After traveling a distance of 252 pixels (8 degrees), the visual target vanished. The auditory target was a single tone. For ascending motion, the auditory target exhibited a smooth change in frequency from 60 Hz to 960 Hz, and for descending motion, the auditory target exhibited a smooth change in frequency from 960 Hz to 60 Hz. The duration of the visual target and auditory target was 2250 milliseconds. There were two congruent conditions (visual ascending and auditory ascending, visual descending and auditory descending) and two incongruent conditions (visual ascending and auditory descending, visual descending and auditory ascending). Each participant received 40 trials (2 visual directions [ascending, descending] × 2 congruency [congruent, incongruent] × 10 replications).

Procedure. Participants pressed a designated key to begin each trial, and the visual target and auditory target simultaneously appeared. After the targets vanished, participants indicated the final position of the visual target by using the mouse to position the cursor at the display location of the remembered final location of the visual target and then clicking a button on the mouse. Participants then indicated the direction of auditory motion (whether pitch ascended or descended) by clicking the mouse on one of two directional arrow keys in the display. Before the experiment, each participant completed a set of training trials.

Results

Data from trials in which an incorrect answer was given regarding the direction of auditory motion were removed, and these amounted to less than 1% of trials.

Consistent with previous research, differences between judged vanishing point and actual vanishing point (on the axis of motion) were referred to as *M displacement*. Positively-signed M displacement indicated judged vanishing point was shifted forward (in the direction of visual motion), and negatively-signed M displacement indicated judged vanishing point was shifted backward (in the direction opposite to visual motion). M displacement larger than zero indicated the presence of RM.

M displacement was analyzed in a 2 (visual direction) × 2 (congruency) ANOVA. As shown in Figure 1, direction was significant, $F(1, 20) = 262.14$, $p < 0.05$, with descending motion leading to more positive M displacement than did ascending motion. Neither congruency nor Direction × Congruency were significant, Fs < 1.

M displacement for descending visual motion was larger than zero if auditory motion was ascending, $t(20) = 13.76$, $p < 0.01$, or descending, $t(20) = 15.84$, $p < 0.01$. M displacement for ascending visual motion was smaller than zero if auditory motion was ascending, $t(20) = -4.13$, $p < 0.01$, or descending, $t(20) = -5.01$, $p < 0.01$.

Discussion

Whether auditory motion was congruent or incongruent with visual motion did not influence M displacement for visual targets, and this is consistent with Hubbard and Courtney (2010). Thus, findings of Hubbard and Courtney were not due to presentation of implied motion or to use of a probe response method. M displacement for descending visual motion was larger than M displacement for ascending visual motion, and this is consistent with previous findings. Indeed, M displacement for ascending visual targets was negative, and so the presence of auditory motion seems to have facilitated effects of visual RG.

Experiment 2

Visual targets and auditory targets were the same as in Experiment 1, but the response collection was different. In Experiment 2, a single visual probe was presented after the visual target and auditory target vanished, and participants judged whether the probe was at the same location as where the visual target vanished or was at a different location. The position of the probe relative to the final location of the visual target varied over trials.

Method

Participants. Participants were 20 individuals from the participant pool used in Experiment 1 (16 female and 4 male, mean age of 28.25 years). All were naïve regarding the hypotheses and reported normal or corrected-to-normal vision and audition.

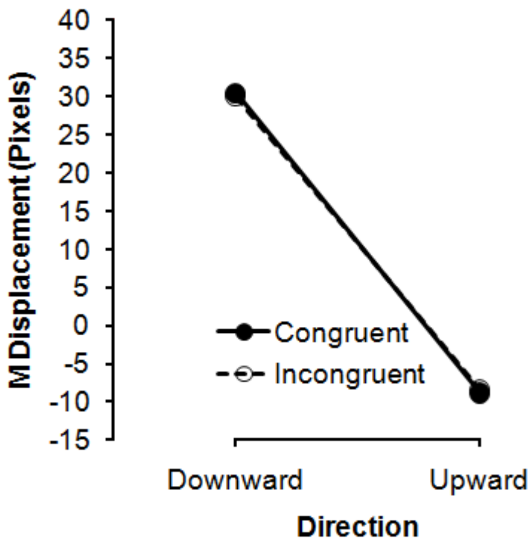

Figure 1. Displacement as a function of direction in Experiment 1.

Apparatus. The apparatus was the same as in Experiment 1, except that a response pad (RB-730) with several keys was connected to the computer and used to record responses.

Stimuli. Visual targets and auditory targets were the same as in Experiment 1. Probes were the same size, shape, and color as the visual target. Probes were at the same horizontal coordinates as the final location of the visual target and at one of nine vertical coordinates relative to the final location of the visual target: -12, -9, -6, -3, 0, +3, +6, +9 or +12. Negatively-signed probes were the indicated number of pixels behind the final location of the target (below an ascending target, above a descending target), and positively-signed probes were the indicated number of pixels beyond the target (above an ascending target, below a descending target). The zero probe was at the same coordinates as the final location of the visual target. Each participant received 216 trials (2 visual directions [ascending, descending] × 2 congruency [congruent, incongruent] × 9 probe positions × 6 replications).

Procedure. The procedure was the same as in Experiment 1, with the following exceptions: Each trial began 250 milliseconds after participants pressed a designated key on the response pad. A probe was presented 250 milliseconds after the visual targets and auditory targets vanished and remained visible until the participant responded. Participants pressed a green key on the response pad if the probe was at the same location as the final location of the visual target and pressed a red key on the response pad if the probe was at a different location than the final location of the visual target. Participants then indicated the direction of auditory motion by pressing either a down arrow key or an up arrow key.

Results

Data from trials in which an incorrect answer was given regarding the direction of auditory motion were removed, and these amounted to less than 1% of trials.

The probabilities of a *same* response as a function of probe position are shown in Figure 2. In congruent trials (left panel), descending trials exhibited a higher proportion of *same* responses for positively-signed probes, whereas ascending trials exhibited a higher proportion of *same* responses for negatively-signed probes. In incongruent trials (right panel), distributions of *same* responses on ascending trials or descending trials were more similar.

Consistent with previous research, estimates of displacement were determined by calculating a weighted mean (WM; the sum of the products of the proportion of *same* responses and distance of the probe from the final location of the moving target, in pixels, divided by the sum of the proportions of *same* responses) for each participant for each condition. The sign of a WM indicated direction of displacement (i.e., a minus sign indicated displacement in the direction opposite to target motion, a plus sign indicated displacement in the direction of target motion), and the absolute value of a WM indicated magnitude of displacement (i.e., a larger absolute value indicated larger displacement). WMs larger than zero indicated the presence of RM.

WMs were analyzed in a 2 (visual direction) x 2 (congruency) ANOVA. As shown in Figure 3, Direction × Congruency was highly significant, $F(1,19) = 13.52$, $p < 0.05$, and neither direction nor congruency were significant. Additionally, t-tests of direction were conducted on congruent trials and incongruent trials, but direction was significant only in congruent trials, $t(19) = 3.08$, $p < 0.025$, with larger displacement for descending targets.

WMs for descending visual motion were larger than zero if auditory motion was descending, $t(19) = 2.26$, $p < 0.05$, but not if auditory motion was ascending, $t(19) = -0.51$, $p > 0.05$. WMs for ascending visual motion were marginally less than zero if auditory motion was ascending, $t(19) = -1.80$, $p < 0.09$, and did not differ from zero if auditory motion was descending, $t(19) = -0.16$, $p > 0.05$.

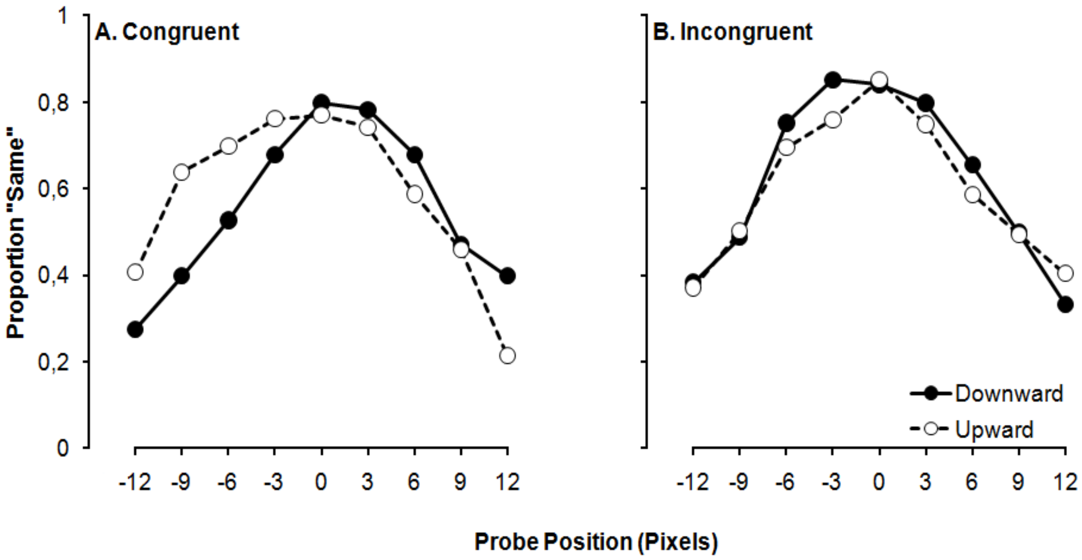

Figure 2. Proportion of *same* responses as a function of probe position for congruent trials (left panel) and incongruent trials (right panel).

Discussion

Robust displacement occurred if visual motion and auditory motion were congruent; displacement was forward for descending motion and backward for ascending motion, and this replicates the findings of Experiment 1. Displacement did not occur if direction of visual motion and direction of auditory motion were incongruent, and this differs from the findings of Experiment 1. Use of a probe methodology appeared to facilitate influence of incongruent auditory motion. However, Hubbard and Courtney (2010) used a probe response measure, and they did not find an overall effect of congruency. It is possible that use of implied motion in Hubbard and Courtney resulted in overall weaker motion signals of visual targets and auditory targets that did not prevent initially stronger visual motion from still influencing auditory RM, but prevented initially weaker auditory motion from influencing visual RM.

General Discussion

The lack of effect of congruency of auditory motion on visual RM and the facilitation of visual RG by auditory motion in Experiment 1 are consistent with Hubbard and Courtney (2010). The effect of direction of auditory motion on visual RM in Experiment 2 (a) suggests RM results from a high-level mechanism, as a combination of information from different modalities is less likely at a low (perceptual) level and more likely at a high (cognitive) level and (b) provides the first evidence of an effect of auditory motion on visual RM. The effect of congruency of auditory motion on visual RM in Experiment 2 is the same as the effect of congruency of

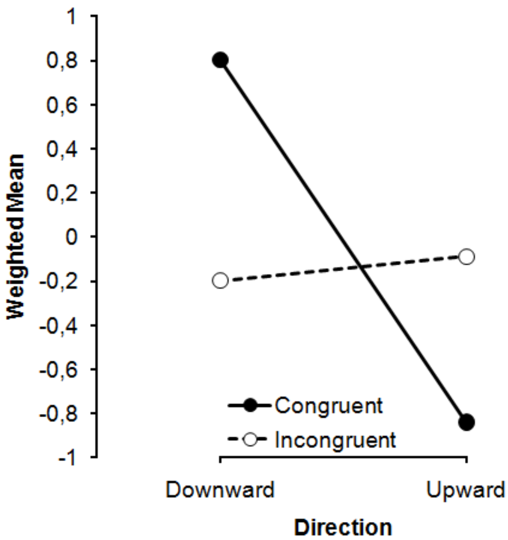

Figure 3. Weighted means as a function of direction in Experiment 2.

nontarget same-modality context in Hubbard (1993), in which a visual surrounding frame that moved in the same direction as a visual target increased RM for the target and a surrounding visual frame that moved in the opposite direction of a visual target decreased RM for the target (as measured by probe judgment). Same-modal and cross-modal nontarget motion influence RM in similar ways, and this is consistent with a high-level mechanism for RM.

Why might an effect of congruency of auditory motion on visual RM be observed if probe judgment is used (Experiment 2) but not if cursor-positioning is used (Experiment 1)? One possibility involves differences between the perception-for-action system and the perception-for-identification system (Milner & Goodale, 1995), such that cursor-positioning involves perception-for-action and probe judgment involves perception-for-identification. The lack of effect with cursor-positioning in Experiment 1 is consistent with relative insensitivity of responses involving the motor system (i.e., perception-for-action) to some visual illusions (e.g., Aglioti et al., 1995; Gentilucci et al., 1996). If modulation of RM occurs in cortical pathways for perception-for-identification or perception-for-action, this would suggest RM involves high-level processes. Hubbard and Courtney did not observe an effect of direction of auditory motion on visual RM if a probe methodology was used, and this might reflect greater activation of "location" information (relevant to perception-for-action) with implied motion.

In addition to the specific empirical contributions noted above, and in conjunction with the findings of Hubbard and Courtney, the pattern of cross-modal influences on RM and RG reported here also provide theoretical contributions suggesting the strength of the motion signal and the involvement of motor processes can modulate displacement.

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