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Online control of reaching and pointing to visual, auditory, and multimodal targets: Effects of target modality and method of determining correction latency

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ABSTRACT

Movements aimed towards objects occasionally have to be adjusted when the object moves. These online adjustments can be very rapid, occurring in as little as 100 ms. More is known about the latency and neural basis of online control of movements to visual than to auditory target objects. We examined the latency of online corrections in reaching-to-point movements to visual and auditory targets that could change side and/or modality at movement onset. Visual or auditory targets were presented on the left or right sides, and participants were instructed to reach and point to them as quickly and as accurately as possible. On half of the trials, the targets changed side at movement onset, and participants had to correct their movements to point to the new target location as quickly as possible. Given different published approaches to measuring the latency for initiating movement corrections, we examined several different methods systematically. What we describe here as the optimal methods involved fitting a straight-line model to the velocity of the correction movement, rather than using a statistical criterion to determine correction onset. In the multimodal experiment, these model-fitting methods produced significantly lower latencies for correcting movements away from the auditory targets than away from the visual targets. Our results confirm that rapid online correction is possible for auditory targets, but further work is required to determine whether the underlying control system for reaching and pointing movements is the same for auditory and visual targets.

1. Introduction

When reaching to point towards or grasp an object, it occasionally moves unexpectedly, or we dislodge it with our hand, or our initial movement was inaccurate. We then have to correct our movement 'online' during its execution. Online control may be the default mode of visuo-motor control, rather than using a model-based or predictive form of control (Zhao & Warren, 2015). Online movement corrections can be very rapid. In cats reaching for a food reward, paw movements can be corrected within as little as 60–70 ms following changes in target location (Alstermark, Eide, Górska, Lundberg, & Pettersson, 1984). In humans, significant changes in reaching movement acceleration have been reported as early as 90 ms after the target displacement (Paulignan, MacKenzie, Marteniuk, & Jeannerod, 1991). The online control of movements has been thoroughly investigated for changes in the location, size, and other features of visual targets (Paulignan, Jeannerod, MacKenzie, & Marteniuk, 1991; Paulignan, MacKenzie, et al., 1991; Veerman, Brenner, & Smeets, 2008; Oostwoud Wijdenes, Gomi, & Brenner, 2015), but the online control of movements towards auditory targets has only just begun to be studied (Boyer et al., 2013; see Cameron & López-Moliner, 2015; Cluff, Crevecoeur, & Scott, 2015, for similar points regarding proprioception). The present study investigated the ability of healthy human participants to make online movement corrections to visual, auditory, and multimodal targets. In particular, we compared the latencies of these corrections. By 'multimodal' target, we mean a target that begins either as visual or auditory, then switches modality after movement onset, to become auditory or visual, respectively.

The online control of movements to visual targets is thought to be a function of the dorsal visual stream: damage to the superior occipital–parietal cortex impairs the online control of reaching movements (Pisella et al., 2000), and targets thought to be

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processed most rapidly by the magnocellular pathway of the dorsal stream are associated with lower latency online control (Veerman et al., 2008). There is little evidence concerning the neural basis of online control of movements towards auditory targets. In macaques, neurons in the parietal and premotor cortices may represent the locations of targets across modalities in a common reference frame, for eye and hand movements (Cohen & Andersen, 2000; Graziano, Reiss, & Gross, 1999). Further, the superior colliculus, which receives inputs from vision, audition, and somatosensation, as well as other brain stem regions has been implicated in the online control of reaching movements in the cat (Alstermark et al., 1984; Pettersson, Lundberg, Alstermark, Isa, & Tantisira, 1997), and in primates (Song, Rafal, & McPeek, 2011; Werner, 1993).

Given that these brain areas thought to be involved in the online control of movement are responsive to multiple sensory modalities, we speculated that some aspects of the online control of movements may be multimodal or supramodal in nature, and, further, that rapid online control may even be possible for targets that change modality as well as location. Changes in target modality such as this might occur in nature, for example with a cat chasing a mouse (Alstermark et al., 1984): As the mouse runs behind an object, it is visually occluded from the cat, but auditory cues may still be available to guide pursuit.

We asked healthy volunteers to make speeded reaching and pointing movements to visual (Experiment 1) and auditory (Experiment 2) targets, which changed location on 50% of the trials (from left-to-right or right-to-left), and, in the third experiment, orthogonally could also change modality (from auditory-to-visual or visual-to-auditory) after movement onset. We determined the time-point at which the movement trajectory changed in the different conditions. Following reviewers' comments, we systematically investigated two different methods of determining latency (statistical, and extrapolation), for three different levels of analysis (whole group, individual participant, and individual trial), and three different types of velocity (lateral, resultant, and statistical components of velocity) – 18 different combinations. For the statistical methods, 61 different statistical thresholds were assessed. This systematic investigation allowed greater certainty in our conclusions, but also highlighted large differences between different methods of estimating correction latency from velocity data.

To summarise, we aimed first to compare different methods of measuring correction latency (see also Oostwoud Wijdenes, Brenner, & Smeets, 2014), second to examine the latency of online corrections for pointing to auditory targets in comparison with visual targets, and third to examine the latencies of movement corrections made to both visual and auditory targets that can change modality and/or position at movement onset.

2. Materials and methods

2.1. Participants

Thirteen participants (7 male, 6 female; 11 right-handed; aged between 20 and 33 years; including two of the authors) took part in the experiments. All of the participants had normal or corrected vision. All participants gave written, informed consent, the experimental procedures were approved by the local ethical review panel at the Hebrew University of Jerusalem, and were in accordance with the Declaration of Helsinki (as of 2008).

2.2. Apparatus and materials

The experiments were performed in a darkened sound-attenuated chamber (Eckel C-26, UK). Participants sat in the middle of the chamber on a straight-backed chair with a horizontal board as a forearm rest supporting a small marker for the starting position in the centre of the chamber (Fig. 1). An arced metal hoop of 90 cm radius supported an array of three loudspeakers (7.5° left, centrally, and 7.5° right of the midline), and three 5 mm diameter LEDs (left, centre, and right, attached centrally in front of each loudspeaker).

Index fingertip and head position (3 degrees of freedom) and orientation (3 degrees of freedom) were recorded with a Polhemus Patriot (Polhemus, Colchester, VT, USA) magnetic tracking system, sampling at 60 Hz. The transmitter was positioned centrally, in front of and below the participant, between their knees. Participants wore plastic goggles which held the head position tracker and a laser pointer, used to assist calibration of head position prior to data collection. Horizontal and vertical electrooculographic (EOG) data were acquired with an Active 2 Biosemi system (Biosemi, Amsterdam, The Netherlands), sampling at 1024 Hz, with an online low-pass filter of 256 Hz. Four electrodes were used for EOG recording: two electrodes for the horizontal EOG, at the outer canthi of the left and right eyes (HEOGL, HEOGR), and two vertical EOG electrodes below (infraorbital, VEOGI) and above (supraorbital, VEOGS) the right eye. Two channels were recorded from the mastoid processes and another from the tip of the nose, but were not used. Bipolar EOG channels were created offline by subtracting HEOGL from HEOGR and VEOGI from VEOGS. The data were referenced online to a common-mode.

2.3. Stimuli

Visual and auditory stimuli were presented by passing the same amplitude-modulated white noise stimulus waveform through the sound card of a PC. A parallel port signal triggered a relay switch box that channelled the stimulus to either a loudspeaker or an LED (5 mm, red, ~800 mcd). The stimulus was generated on each trial as follows: a 1250 ms white noise signal sampled at 44,100 Hz, ranging from −1 to +1 was attenuated by 5% to prevent clipping, and shaped with a trapezoidal envelope providing 10 ms rise and fall times. To facilitate the perceptual localisation of the auditory stimuli, the stimulus was multiplied by a sinusoidal envelope with a frequency of 60 Hz, providing an amplitude-modulation depth of 80%. Thus, perceptually, the auditory stimulus

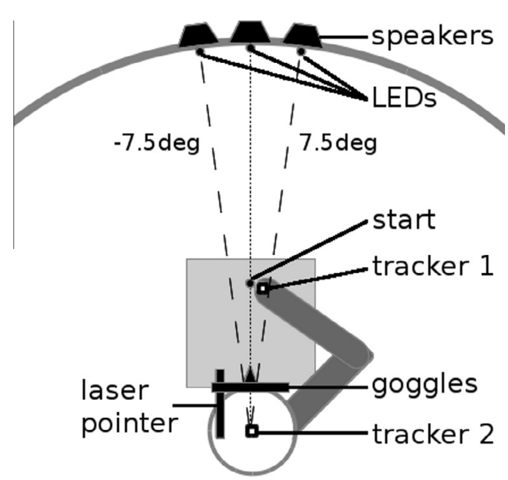

Fig. 1. Experimental apparatus. Participants sat at the centre of a 90 cm radius metal hoop (grey arc) supporting three loudspeakers (filled trapeziums) and three LEDs (filled circles) at the centre, and 7.5° to the left and right of the participant's midline. Participants rested their hand on a starting board (grey rectangle), keeping their index finger in a 'start' location (filled circle). Participants wore a tracker on their index finger and vertex (solid squares), and a pair of goggles supporting a laser pointer (filled rectangles).