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Hitting a target is fundamentally different from avoiding obstacles

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ABSTRACT

To successfully move our hand to a target, it is important not only to consider the target of our movements but also to consider other objects in the environment that may act as obstacles. We previously found that the time needed to respond to a change in position was considerably longer for a displacement of an obstacle than for a displacement of the target (Aivar, Brenner, & Smeets, 2008. Experimental Brain Research 190, 251–264). In that study, the movement constraints imposed by the obstacles differed from those imposed by the target. To examine whether the latency is really different for targets and obstacles, irrespective of any constraints they impose, we modified the design of the previous experiment to make sure that the constraints were matched. In each trial, two aligned 'objects' of the same size were presented at different distances to the left of the initial position of the hand. Each of these objects could either be a *target* or a *gap* (opening between two obstacles). Participants were instructed to pass through both objects. All possible combinations of these two objects were tested: gap–target, target–gap, gap–gap, target–target. On some trials one of the objects changed position after movement onset. Participants systematically responded faster to the displacement of a target than to the displacement of a gap at the same location. We conclude that targets are prioritized over obstacles in movement control.

1. Introduction

In daily life our movements are not only determined by the objects that we are interested in, but also by the many surrounding objects that can be considered as obstacles for reaching the object of interest. Many studies have shown that obstacles close to the path to a target have an effect on the movement trajectory (Chapman & Goodale, 2008, 2010b; Mon-Williams et al., 2001; Sabes & Jordan, 1997; Saling et al., 1998; Tipper, Howard, & Jackson, 1997; Tipper, Lortie, & Baylis, 1992; Tresilian, 1998; Verheij, Brenner, & Smeets, 2014). In our dynamic environment, in which there are other actors besides ourselves simultaneously trying to perform different goal-directed actions, objects can change position and suddenly appear in the path to our goal. Many studies have shown that people can respond very quickly (in about 120 ms) when the position of the target of the movement changes unexpectedly (Brenner & Smeets, 1997, 2003, 2004; Day & Lyon, 2000; Oostwoud Wijdenes, Brenner, & Smeets, 2011; Prablanc & Martin, 1992; Soechting & Lacquaniti, 1983; Veerman, Brenner, & Smeets, 2008). It has also been shown that we take obstacles into account when responding to changes in target position during the movement (Chapman & Goodale, 2010), and when responding to mechanical perturbations of the arm (Nashed, Crevecoeur, & Scott, 2012). However it is still not clear how quickly hand movements can be adjusted in response to a change in the position of other objects than the target, such as obstacles.

In a previous study, we examined how obstacles and targets are dealt with in dynamic environments by analyzing hand movement corrections in two kinds of trials: trials in which the target was displaced and trials in which one or more obstacles were displaced (Aivar, Brenner, & Smeets, 2008). In one case (Experiment 1), participants had to reach the target through a gap between the obstacles. In 60% of the trials either the target jumped 2 cm or the obstacles jumped so that the gap moved 2 cm. Under these conditions we found that on average the correcting response occurred 150 ms after the *target* jumped, while on average it occurred 180 ms after the *obstacles* jumped (Aivar, Brenner, & Smeets, 2008; Fig. 2). The slower response to the displacement of the obstacles was surprising because the hand had to pass the obstacles *before* reaching the target. We interpreted these results as suggesting that obstacles are processed with longer latencies than targets. The latency differences could be the result of differences between the time it takes to process visual information about targets and obstacles. Alternatively, the latency differences could

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have to do with the different constraints that the targets and obstacles imposed on the hand's trajectory. Targets and obstacles differed in several respects in our previous study. Targets were always white, 4 cm long rectangles, while obstacles had different sizes and moved differently in each of the reported experiments (see Fig. 1 of Aivar, Brenner, & Smeets, 2008).

The main purpose of the present study was to examine whether the latency is different for targets and obstacles, irrespective of any kinematic constraints. In each trial, the task was to move through two equally sized ranges of positions (which we refer to as 'objects'), which could each either be a *target* or a *gap*. *Targets* were rectangles whereas *gaps* were rectangular spaces between obstacles. Participants were instructed to hit the targets and pass through the gaps. In separate experiments we tested different combinations of objects (targets and gaps).

2. General methods

The two main experiments and a third, control experiment, were all performed with the same procedure and equipment, and the data was analyzed in the same way. We will therefore present the general methods in this section and specify the few things that differed between experiments later on.

2.1. Participants

All participants reported having normal or corrected to normal vision, to be right-handed, and to have no known neuromuscular deficits. All participants gave their informed consent to participate in the experiment, which is part of an ongoing research project that has been approved by the ethics committee of the Faculty of Human Movement Sciences of VU University in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

2.2. Set-up

We used a graphic tablet (Wacom A2) to record the two-dimensional position of a hand-held stylus at a frequency of 200 Hz throughout the experiments. The graphic tablet was placed horizontally on a standard table. Participants sat comfortably in a chair in front of the graphic tablet and held the stylus in their right hand. Stimuli were projected onto a surface above the tablet that was visible through a semi-transparent mirror so that the image appeared to be on the tablet. Lamps illuminating the space between the mirror and the tablet allowed participants to also see their hand during the experiments. The resolution of the display was 1024×768 pixels, with each pixel corresponding to approximately 0.5 mm on the surface of the tablet.

2.3. Task

The task was to slide a stylus from right to left across the graphic tablet while moving through two objects. At the beginning of each trial a red circle (1 cm diameter), indicating the *starting position*, was presented on the right side of the tablet. The rest of the tablet was empty. Soon after the stylus was placed at the starting position, the two objects that one was to move through were presented simultaneously on the tablet. This was the signal to begin the movement through *both* objects. The combinations of targets and gaps that could serve as pairs of objects varied between experiments. The first object was always 25 cm to the left of the starting position, while the second was always 5 cm further to the left, so the hand mainly had to move laterally. A target was a 4×1 cm rectangle that was oriented so that the long side was orthogonal to the movement direction (represented in blue in Fig. 1). A gap consisted of two aligned large rectangles (19×1 cm) with a 4 cm gap between them (represented in red in Fig. 1).

At the beginning of each trial, both objects were aligned with the starting position. In 20% of the trials neither object moved. In the remaining trials (perturbation trials) either the first object or the second object jumped to a new position. This jump occurred 350 ms after the stimuli were presented. Its amplitude was always 2 cm in a sagittal direction, perpendicular to the main direction of movement. Half the jumps were away from the participant and the other half were towards the participant. We expect responses to such jumps in the sagittal direction. On most trials the hand was already moving when the jump occurred (if not, the trial was not analyzed; see below). On average the hand position at the time of the jump was less than 4 cm from the starting position. Trials were considered to have ended once the stylus moved further than 30 cm to the left of the starting position (i.e. once it passed the second object).

Participants were instructed to perform fast movements but also to always avoid the obstacle(s) (i.e. to pass through the gap) and hit the target(s). It was emphasized that it was as important to hit targets as to avoid obstacles. The hand, targets and obstacles were continuously visible during the movement. After each trial, feedback was presented in the form of a message on the screen informing participants about their performance. This feedback was positive if all targets were hit and obstacles avoided, and the movement was completed within 800 ms. Otherwise, negative feedback specified whether the movement took longer than 800 ms, an obstacle was hit, or a target was missed.

Participants performed 4 blocks of 50 trials each in a single continuous session. The configuration remained the same for all trials within a block. In each block the five different perturbations (static plus four different jumps) were each presented 10 times in random order. Each of the two configurations that were used in an experiment was presented in two of the four blocks. Block order was counterbalanced across participants. Thus, each participant performed a total of 200 trials (two blocks of 50 trials per configuration) in a single session that lasted about 20 min. Of the 100 trials that were recorded for each of the two configurations within a session, 20 trials were static and 80 were perturbed (each combination of 2 objects that could jump and 2 possible directions of the jumps occurred 10 times in each of the 2 blocks).

2.4. Data analysis: movement kinematics

We only considered trials in which the hand started to move before the jump occurred and moved 30 cm to the left (ending the trial) within 800 ms. All trials that met these conditions were included in the analysis, regardless of other aspects of performance. We evaluated the overall performance by calculating the percentage of obstacle hits and target misses for each kind of perturbation. We did so for each of the configurations that were presented.

The measured tablet positions were used to obtain movement paths and velocity profiles. We calculated velocities by dividing the distance between consecutive samples by the sampling interval (5 ms). Occasional missing data points were estimated by linear interpolation. No other smoothing algorithms were used, so the original temporal resolution of the measurement was not compromised. To determine the start of the movement for each trial, the peak in the tangential velocity profile was found and then the beginning of the movement was determined by looking backwards in time for the last velocity value that was not 0. As already mentioned, the end of the movement was when the stylus passed the