Acta Psychologica 150 (2014) 94–99

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

The influence of object identity on obstacle avoidance reaching behaviour

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ARTICLE INFO

Article history:
Received 29 August 2013
Received in revised form 13 April 2014
Accepted 20 April 2014
Available online 21 May 2014

PsycINFO classification:
2323
2330
2320
2300
2221

Keywords:
Obstacle avoidance
Object identity
Peripersonal space
Non-spatial

ABSTRACT

When reaching for target objects, we hardly ever collide with other objects located in our working environment. Behavioural studies have demonstrated that the introduction of non-target objects into the workspace alters both spatial and temporal parameters of reaching trajectories. Previous studies have shown the influence of spatial object features (e.g. size and position) on obstacle avoidance movements. However, obstacle identity may also play a role in the preparation of avoidance responses as this allows prediction of possible negative consequences of collision based on recognition of the obstacle. In this study we test this hypothesis by asking participants to reach towards a target as quickly as possible, in the presence of an empty or full glass of water placed about half way between the target and the starting position, at 8 cm either left or right of the virtual midline. While the spatial features of full and empty glasses of water are the same, the consequences of collision are clearly different. Indeed, when there was a high chance of collision, reaching trajectories veered away more from filled than from empty glasses. This shows that the identity of potential obstacles, which allows for estimating the predicted consequences of collision, is taken into account during obstacle avoidance.

1. Introduction

When reaching out for target objects, we rarely collide with other objects in our peripersonal space, even though our environment is usually cluttered with objects. Although this obstacle avoidance occurs effortlessly, and often unconsciously, visual information about the location of potential obstacles needs to be incorporated into motor plans and execution. As a result, the presence of these objects influences both the spatial and temporal parameters of reaching trajectories. Even when non-targets are not actually physically obstructing the movement, hand movement trajectories show a tendency to veer away from non-target objects situated in the workspace (Chapman & Goodale, 2008; McIntosh, McClements, Dijkerman, Birchall, & Milner, 2004; Menger, Van der Stigchel, & Dijkerman, 2012; Rice et al., 2008; Tipper, Howard, & Jackson, 1997; Tresilian, 1998). For instance, Tipper et al. (1997) showed that reach-to-grasp movements deviated away from non-target objects that were not physically restricting the reach in a manner similar (but to a smaller extend) as when they were actually obstructing the movement. Furthermore, hand movements are slowed down when there are nearby obstacles (see for instance Biegstraaten, Smeets, & Brenner, 2003; Chapman & Goodale, 2008; Jackson, Jackson, & Rosicky, 1995; Mon-Williams et al., 2001; Saling, Alberts, Stelmach, & Bloedel, 1998; Tipper et al., 1997; Tresilian, 1998). Probably, these effects of obstacles in peripersonal space on hand movements allow us to avoid knocking them over (Menger et al., 2012; Mon-Williams et al., 2001; Sabes & Jordan, 1997; Tresilian, 1998). When the likelihood of collision increases, for instance when obstacles are larger or closer to the intended path, hand movements are even slower and deviate more (Biegstraaten et al., 2003; Chapman & Goodale, 2008; Menger et al., 2012; Mon-Williams et al., 2001; Tresilian, 1998). For instance, Mon-Williams et al. (2001) asked participants to grasp an object in the presence of an obstacle that could be placed on one of four (or none of the) locations. All obstacles were presented left or right of the centre line, either flanking the target object or about half-way between the target and the starting point. Their results showed that obstacles altered movements in a way that decreased the risk of collision. When an obstacle was present, movement times increased and grip aperture decreased. With the obstacles closer to the participant a large effect was seen on movement times, and a relatively small effect on grip aperture, and vice versa with flanking obstacles. Similarly, higher obstacles caused larger deviations in the hand trajectories than smaller obstacles when placed mid-reach, but not when they were

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http://dx.doi.org/10.1016/j.actpsy.2014.04.007
0001-6918/

placed at the same depth as the target (Chapman & Goodale, 2008). More recent, Menger et al. (2012) showed that when keeping the visual setup of the workspace constant but varying the chance of collision by manipulating starting posture, the obstacles with the highest chance of collision altered hand trajectories the most.

Changes in the (relative) spatial properties of the workspace thus influence obstacle avoidance, probably by influencing the perceived risk of collision. However, the consequences of a potential collision can be quite different depending on the obstacle. Not only the spatial features, but also the identities of non-target objects are relevant when avoiding obstacles (Schindler et al., 2004). For example, potentially colliding with a cactus is quite different from potentially colliding with a box of tissues, and presumably requires incorporating a different safety margin into one's movement. Therefore, non-spatial object features may also play a role in planning or programming avoidance responses, as this would enable one to predict the possible negative consequences of collision (as suggested by Chapman & Goodale, 2008, 2010; Schindler et al., 2004).

It is still a topic of debate whether the preparation of a movement is one monolithic 'planning system' (Glover, 2004) or should be considered more diverse (Goodale & Milner, 1992; Milner & Goodale, 2008). Both models, however, seem to agree that online control of movements is influenced by spatial, size and shape features processed in the dorsal stream (see also Chapman & Goodale, 2010). Furthermore, both models agree that non-spatial object features that require visual recognition, such as the fragility of an object, are mediated by ventral stream processes and are incorporated in the planning of a movement. This incorporation would allow for preparation of a movement that suits the specific context. Most studies on obstacle avoidance favour a crucial role for dorsal stream processing in using visual input about the obstacle to automatically alter movements (Humphreys & Edwards, 2004; McIntosh et al., 2004; Rice et al., 2006; Schindler et al., 2004). For instance, Schindler et al. (2004) showed that the automatic alteration of reach trajectories to avoid near non-target objects was impaired in two patients with optic ataxia following dorsal stream damage. However, this does not mean that the processing of non-targets in obstacle avoidance is regulated entirely by the dorsal stream. Since non-spatial aspects of obstacles are relevant for predicting the possible consequences of collision, we expect effects on the planning or programming of obstacle avoidance movements.

Indeed there is some evidence that non-spatial features of nontarget objects influence visuomotor performance. In a study by Gentilucci, Benuzzi, Bertolani, and Gangitano (2001), participants reached to grasp a red or a green target object from one of two possible target locations. In half of the trials, a flat distractor (also red or green) flanked the target. The colour of non-targets influenced the grasp (with smaller finger apertures when target and non-target had different colours), but not the reach component of the movement. However, since non-target objects were at the same depth as the target, they were not actually potential obstacles during the reaching part of the movement, although they could be considered potential obstacles while grasping. In a recent study Menger, Dijkerman, and Van der Stigchel (2013) placed a non-target object halfway in between the starting position and the target object and varied colour similarity between the two objects. When target and non-target were dissimilar in colour, participants veered away more during the reaching movement. No effect of colour per se was observed. The effect of similarity was only present when the non-target was placed on the right side where it served more as an obstacle to the trailing arm.

These studies suggest that non-spatial object features influence obstacle avoidance when these features are directly relevant for visuomotor performance. The question remains, however, whether processing of non-spatial information about non-target objects, which allows for estimating the potential consequences of collision, influences obstacle avoidance. We tested this by asking participants to reach towards a target in the presence of an empty or a full glass of water, thereby varying the consequences of collision while keeping spatial features constant. We expected that hand movements would veer away more from filled than from empty glasses, since the predicted consequences of knocking over a filled glass are worse than those of knocking over an empty glass.

2. Methods

2.1. Participants

Seventeen undergraduate, graduate and PhD students of Utrecht University (five males, mean age 24.9 ± 5.0 years) participated in this study and received either a small payment or course credits as compensation for their time. They were naïve to the purpose of the study and gave their informed consent to the experiment. All participants were right-handed, as measured by a Dutch handedness questionnaire (score 9.6 ± 0.7 on a −10 (extremely left-handed) to 10 (extremely right-handed) scale) (Van Strien, 1992). This study was conducted in accordance with the guidelines of the local ethical medical board and the declaration of Helsinki.

2.2. Experimental setup

Participants were seated behind a custom made white table (122 × 61 cm) with an orange button at 8.6 cm from the edge (starting position), and a dark grey target button (22 × 5 cm) at 40 cm from the starting position, at the same level as the table top. Non-targets were placed at 22 cm from the starting position, at 8 cm either left or right of the line between the starting position and the centre of the target button (virtual midline) (see Fig. 1). This distance was chosen because it has been shown to cause reliable obstacle avoidance effects (see for instance McIntosh et al., 2004; Rice et al., 2008; Schindler et al., 2004), while the object is not actually blocking the direct path from the starting position to the target. The non-targets consisted of transparent long-drink glasses with a height of 16.7 cm and a diameter of 6 cm. A felt adhesive circle with the same colour as the table (white) was attached to the bottom of the glasses to be able to put them on the table without making noise.

For each trial, participants were to reach from the starting position and press the target button as fast as possible. Reaching trajectories were recorded at two locations (middle finger tip and centre of the hand) using an electromagnetic motion analysis system (MiniBIRD, Ascension Technologies). This recorded x, y and z positions of two motion sensors at a frequency of 103.3 Hz. The sensors were attached with medical tape to the finger and hand, as well as to the arm of the participant and the edge of the table, to ensure that movements were not restricted by the cables.

Vision was controlled by spectacles with shutter glasses (Plato glasses, Translucent Technologies). Participants could always see their hands and setup within trials (so when moving), but vision was restricted in-between trials.

2.3. Procedure

Participants were seated in a normally lit room and first completed the handedness questionnaire and the Dutch version of the BIS/BAS questionnaire (translated version see Franken, Muris, & Rassin, 2005; original English by Carver & White, 1994; the BIS/BAS questionnaire is generally used to measure the relative sensitivity of the behavioural approach and avoidance system. Since these individual differences were not the focus of this study, and the BIS/BAS score did not correlate with obstacle avoidance in our experiment, it will not further be discussed).

Participants were asked to sit straight behind the table and place their middle finger on the starting position (wrist as straight as possible). At the beginning of each trial the shutter glasses opened, and the