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Master Neuropsychology

Thesis

Obstacle avoidance involves ventral stream functioning: the effect of obstacle identity on reach movements

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Abstract

The mechanisms involved in obstacle avoidance have been thoroughly investigated. Most recent studies have suggested that the dorsal stream is responsible for visual guidance during obstacle avoidance. The aim of this current study was to investigate the effect of object identity during obstacle avoidance by examining the effect of obstacle identity on reach movements. 19 healthy subjects were administered to reach for a target object in the presence of a glass with or without water. Results showed that the location of the glass influenced reach deviations. We also found that obstacle identity influenced maximum deviations in the early stages of reach movements. We conclude that object identity can be used for the visual guidance during avoidance of potential obstacles.

Introduction

Reach movements are influenced by non-goal objects, which can be constructed as potential obstacles. When we do not want to hit an irrelevant object while reaching, we will have to avoid these obstacles. To prevent collisions, our visuomotor system programs a tendency into our movements to veer away from non-target objects. This tendency can be seen in the trajectory of the reach movement and is called obstacle avoidance (Schindler, Rice, McIntosh, Rossetti, Vighetto & Milner, 2004; McIntosh, McClements, Schindler, Cassidy, Birchall and Milner, 2003; James, Culham, Humphrey, Milner and Goodale, 2003).

When we reach out for an object, our arm is directed towards the target by visuomotor networks in our brain. Visual information travels from the occipital visual areas to the parietal and temporal lobes. Identification of the parietal- and temporal visual pathways led researchers on a search for the possible functions of each. Milner and Goodale (1995) proposed a "what" function (to identify what a stimulus is) for the temporal visual pathway and a "how" function (to use visual information to control movement) for the parietal visual pathway. The distinction between these two functions came from an analysis of the neuropsychological deficits after lesions to either stream (Goodale, Meenan, Bülthoff, Nicolle, Murphy, & Racicot, 1994) and from single cell recordings in monkeys (Haxby, Grady, Horwitz, Ungerleider, Mishkin, Carson, Herscovitch, Schapiro, & Rapoport, 1991; Ungerleider, & Haxby, 1994).

For instance, patients who suffer from bilateral superior parietal damage (optic ataxia) are impaired to direct their reaches toward target objects due to the impairment of the parietal visual pathway (the 'dorsal stream') (Schindler et al. 2004). Schindler and colleagues

(2004) tested two patients with optic ataxia by asking them to reach for a target object in the presence of non-target objects. Results showed that they took no account of the obstacle positions while reaching. In contrast to optic ataxia, visual form agnosia is associated with damage to the ventral stream of processing. Rice, McIntosh, Schindler, Mon-Williams, Démonet & Milner (2006) tested patient DF who suffered severe bilateral damage to her occipitotemporal visual system (the `ventral stream'). DF and 6 healthy subjects were asked to reach out and pick up a target object in the presence of obstacles placed at varying distances to the left or right of the target. Results showed that DF shifted her reach trajectories in a manner comparable to healthy subjects (both DF and the healthy subjects shifted their trajectories to the right in the presence of a left obstacle, and shifted their trajectories to the left in the presence of a right obstacle). This means that intact obstacle avoidance behavior is achieved by virtue of her functioning dorsal stream of visual processing. So the absence of dorsal stream functioning in patients with optic ataxia and the preserved dorsal stream functioning in patients with visual form agnosia show that intact dorsal stream functioning is vital for successful obstacle avoidance behavior. The ventral stream appears to play no significant role in visual guidance while avoiding objects.

McIntosh and colleagues (2003) tested a patient with left visual extinction by asking him to reach for a target object in the presence of non-target objects. Extinction is an attentional disorder in which patients fail to report stimuli on the side of space opposite a brain lesion under conditions of bilateral stimulation. The patient avoided obstacles during reaching, to exactly the same degree, regardless of whether he was able to report their presence. This implicit processing of object location, which may depend on spared superior parietal-lobe pathways (dorsal stream), demonstrates that conscious awareness is not necessary for normal obstacle avoidance.

Patients with visual neglect fail to report or respond to visual stimuli from one side of space, typically the left side following right hemisphere damage. Milner and Goodale (1995) stated that the symptoms of neglect reflect a malfunction in a high-level representational structure. McIntosh, Dijkerman, Mon-Williams & Milner (2004) and McIntosh, McClements, Dijkerman, Birchall, & Milner (2004) showed that obstacle avoidance is preserved in patients with left visual neglect, because of intact dorsal stream functioning. These studies of patients with visual neglect suggest that obstacle avoidance functions successfully without the involvement of the ventral stream. Overall, these findings suggest that dorsal stream processes are responsible for obstacle avoidance during visually guided movements and that the ventral stream does not seem to be involved. The aim of this research is to test this hypothesis and to learn more about the influence of object identity during obstacle avoidance.

Several authors have commented on the possible role of the ventral stream in obstacle avoidance. Schindler and colleagues (2004) and Goodale and Milner (1992) reasoned that the ventral stream could be involved in the perceptual recognition of obstacles. The information from the ventral stream is necessary when an object is fragile or harmful. If the object is fragile indeed, the reach trajectory will be wider and the movement time will be longer. This means that different properties of obstacles lead to an alteration of the reach trajectory and movement time. McIntosh and colleagues (2004) stated that an intact ventral stream is necessary to react appropriately to more complex stimuli, because the dorsal stream cannot operate fully successfully in isolation. A more detailed perceptual analysis is required to interpret details of the situation, e.g. the parts of an object to avoid. Although neuropsychological studies so far suggest that the ventral stream is not involved in obstacle avoidance, according to Schindler and colleagues (2004) and Tipper, Howard & Jackson (1997), the properties and the identity of an obstacle influence motor reach and grasp movements to a target object.

In this study, we investigated the influence of obstacle features on reach movements. Particularly, the effect of identity and physical features of an obstacle on reaching movements were assessed. In this study we examined what effect an obstacle (glass) with an important non spatial physical feature (filled with or without water) has on three dependent variables: deviation when crossing the obstacle, maximal deviation of the movement trajectory and reaction time. The subjects sat in front of a wooden table with a wooden block placed at the end. A glass with or without water was placed in front of the wooden block. Subjects had to avoid the glass while they reached for the block. If object identity is important for obstacle avoidance, we expect wider deviations when the hand crosses the obstacle if the glass is filled with water. This would mean that information from the ventral stream about the properties of the glass is used for adjusting the movement to prevent the hand to collide with the glass. An answer to these hypotheses provides more insight in the involvement of the ventral stream during obstacle avoidance. We suggest that information from the ventral stream influence our motor reach movements in case the reach movements in our experiment indeed deviate as predicted.

Methods

Subjects

19 healthy, right-handed subjects were recruited from the Utrecht University (mean=21.58, SD=2.63). They had normal visual abilities and they did not know about the goal of the experiment. They received a reward (7 euro) for their participation.

Apparatus and Materials

The subjects were seated in front of a table with a big wooden plate (122 x 61 cm) on top of it. Their right hand had to be placed on the spacebar of the keyboard, that served as a home position (see figure 1, red dot). A wooden block (brown rectangle; 17 x 4.5 x 4.5 cm) at the end of the plate was used as target object. Spectacles with shutter glasses (Plato glasses, Translucent Technologies) ensured the subject could not see the set-up until the start of the trial. An electromagnetic motion analysis system device (Minibird, Ascension Technologies) was placed in the right corner underneath the wooden plate to measure the trajectory of the reach movement. The minibirds (wired to the sensor markers on the forefinger and thumb) registered the trajectory of the reach movement at a frequency of 100 Hz. The reach movements were recorded in a Y, X and Z-axis (length, width and height of the reach movement). A computer with stimulus delivery and experimental control software (Presentation) transmitted codes to the spectacles for opening and closing the glasses for every trial and registered reaction and movement times. Another computer registered the data from the sensory markers (minibirds).

A transparent plastic glass (blue circles represent four different positions; 11 x 7.5 x 7.5 cm) with or without water served as an obstacle. Small wooden blocks (yellow rectangles; 11 x 6.5 x 2 cm) were placed at the left and right side of the table, as neutral obstacles to ensure the reach movement did not deviate from the referred trajectory.

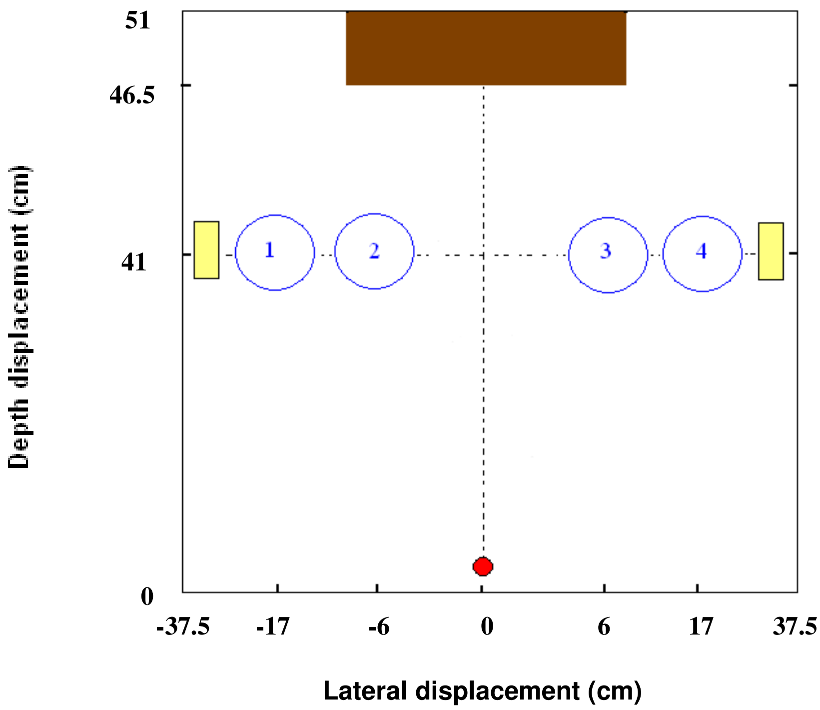

Figure 1. *Plan view of the apparatus used in the experiment. The blue circles represent the four possible locations of the glass. The red dot represents a spacebar which served as start position. The brown rectangle is the target object subjects had to reach for. The yellow rectangles represent wooden blocks that served as neutral obstacles. The horizontal dotted line is the virtual width of the four glasses. The vertical dotted line represents the virtual zero line. X- and Y-axis presented with different intervals.*

Design and conditions

The experiment was a 4x2 within subject design. The plastic glass could be placed on four different positions on the imaginary horizontal line and there were two conditions of the obstacle; one with a full glass of water and the other with an empty glass. The positions of the glasses were left far (circle number 1; placed at an angle of 35° to the left of the center of the starting position), left middle (circle number 2; placed at an angle of 20° to the left of the center of the starting position), right middle (circle number 3; placed at an angle of 20° to the right of the center of the starting position) and right far (circle number 4; placed at an angle of 35° to the right of the center of the starting position). There were 80 trials per subject and the conditions were randomized. Presentation software shuffled all of the stimuli in a random order. This feature also ensured that every subject got a different order of stimuli.

Procedure

Before the start of the experiment, each subject was given instructions about what was going to happen. The subject was asked to reach for the wooden log at the end of the table as quickly as possible. They were instructed not to pay specific attention to the glass that was placed in front of the wooden log and that they had to reach passed them. The subject started with the right forefinger placed on the space bar. Until the start of each trial, the glasses were opaque. When the glasses opened, the subjects had to reach for the log. The subjects initiated the trial by releasing the space bar. The reaching movement was recorded using the electromagnetic motion analysis system device.

Statistical Analysis

Three repeated measures ANOVAs were carried out (using SPSS 13.0). There were two independent variables; the 'identity of the obstacle' and the 'position of the glass'. The first independent variable contained two levels: a full glass or an empty glass. The second independent variable contained four levels: extreme left, left middle, right middle and extreme right. The dependent variable of the first repeated measure ANOVA was 'deviation when crossing the obstacle' (cm). 'Maximum deviation' (cm) was the dependent variable for the second repeated measure ANOVA and 'reaction time' (ms) was the dependent variable for the last repeated measure ANOVA.

Each trial was considered to have a complete registration of the outward movement. Also, the reach movement had to be registered with as little noise as possible. The outward movement was registered appropriately when the experiment leader pressed the record button before the subject reached. Some trials contained too much noise, caused by a movement that went beyond the wooden log (and consequently beyond the reach of the minibird device). Because of an incomplete registration or too much noise, data from some subjects had to be eliminated (7.91 %). Due to the Presentation shuffle feature, not all conditions were equally divided among subjects. Data from subjects with only one or no trials per condition were eliminated. A total of twelve subjects provided adequate data; data outliers from seven subjects deviated significantly (> 2 SD) and were excluded.

1. Deviation from the zero line when crossing the obstacle

The trajectory of the reach movement was analyzed with MATLAB (R2008a). The dependent variable for each trial was the position of the marker as it crossed the virtual horizontal line joining the four locations of the glasses (Figure 1). The virtual straight line from the start position to the wooden block at the end of the table was defined as the zero (0) line. The X value belonging to the position of the marker as it crossed the virtual horizontal line minus the X value of the zero line provided a deviation left or right from this zero line. Negative deviations to the left were marked with a “-”, and positive deviations indicated deviations to the right. Means of all deviations per condition were calculated for every subject.

2. Maximum deviation from the zero line

The dependent variable for each trial was the maximum absolute deviation with reference to the zero line. First, maximum X values for every outward movement were selected. Then, the maximum deviation was calculated by subtracting the X value of the zero line from the maximum X value. Negative deviations to the left were marked with a “-”, as positive deviations to the right were not marked. Means of all maximum deviations per condition were calculated for every subject.

3. Reaction time

The dependent variable for each trial was the time between the opening of the shutter glasses and the release of the space bar. Reaction time was registered in the log files for each trial per subject.

Results

1. Deviation from the zero line when crossing the obstacle

The first dependent variable for each trial was the position of the marker as it crossed the virtual horizontal line joining the four locations of the glasses (figure 1). The independent variables were location of the obstacle (left far "LL", left middle "L", right middle "R" and right far "RR") and identity of the obstacle (water, no water).

A repeated measures ANOVA showed a significant effect of location of the obstacle [$F(3,9) = 11.871$, $P = 0.002$]. Paired Sample T-tests were conducted to investigate which locations differed significantly from each other. Every location of the glass differed significantly from each other with regard to deviation from the zero line when crossing the obstacle (p's<0.05). Figure 2 shows that location LL caused little deviation in the reach trajectory (mean=-0.74 mm, SD=22.55), whereas location L caused the reach trajectory to deviate almost 30 mm to the right (SD=22.18). When the glass stood at location R, the reach trajectory deviated 33 mm to the left (SD=29.59). Finally, when the glass stood at location RR, reach trajectories deviated 12 mm to the left (SD=20.43). No effect of identity was found [$F(1,9) = 0.053$, $P = 0.823$], so whether a glass was full or empty seemed to have no effect on deviations from the zero line. Finally, no interaction effect was found [$F(3,9) = 1.26$, $P = 0.345$].

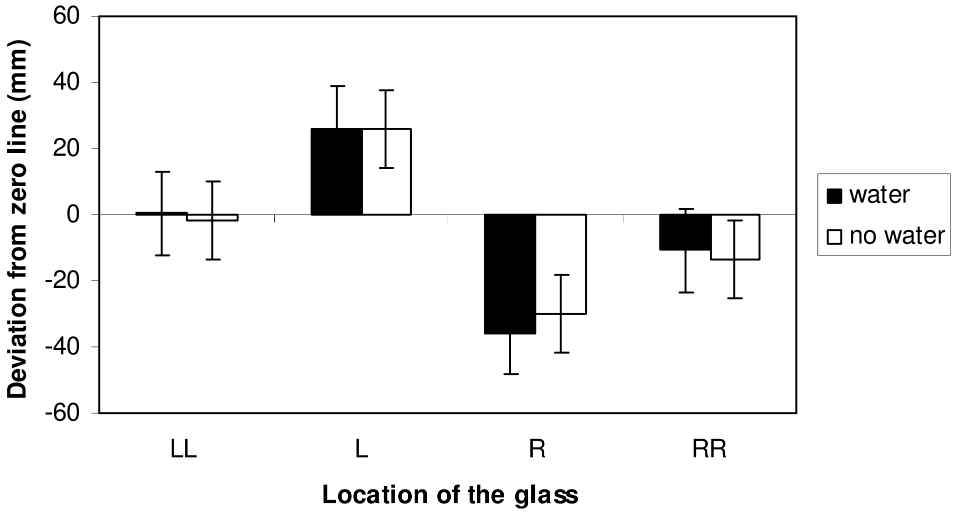

Figure 2. *Deviation means from the zero line of the location of the obstacle (standard errors indicated). Deviations to the right are positive; deviations to the left are negative.*

2. Maximum deviation from the zero line

The second dependent variable for each trial was the maximum absolute deviation with reference to the zero line. A repeated measures ANOVA showed a significant effect of location of the obstacle [F(3,9) =9.964, P = 0.003] and of identity of the obstacle [F(1,11) = 5.603, P = 0.037]. Paired Samples T-tests of location of the obstacle showed significant differences between LL and L, LL and R, L and R and finally R and RR (p's < 0.05). This means that these positions differed significantly from each other with regard to maximum deviation from the zero line. For example, wider deviations occurred when the glass stood at location L than when the glass stood at location LL. The smallest deviations occurred when the glass stood at location LL (mean=34 mm, SD=14.60), while the widest deviations occurred when the glass stood at position R (mean=60 mm, SD=19.79).

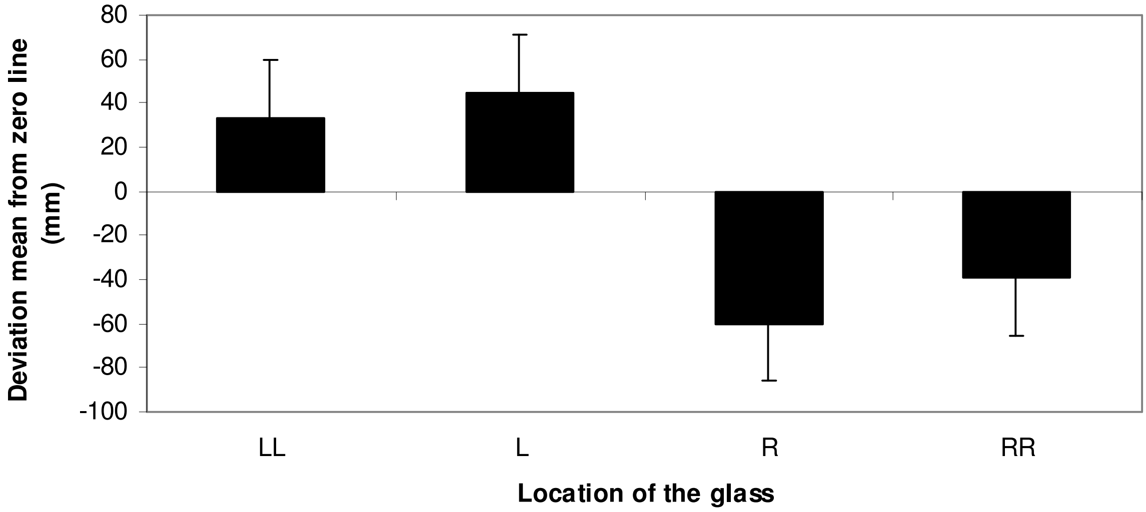

Figure 3. *Maximum deviation means of location of the obstacle (standard errors indicated). Deviations to the right are positive; deviations to the left are negative.*

The significant effect of identity of the obstacle (Figure 4) showed that maximum deviation differed significantly between a full and an empty glass of water. Reach trajectories veered further away from the zero line in case the glass was filled with water (mean difference = 2.98 mm, SD = 10.47) compared to reach trajectories which deviated away from an empty glass. Finally, no significant interaction effect was found [F(3,9) = 2.703, P = 0.108].

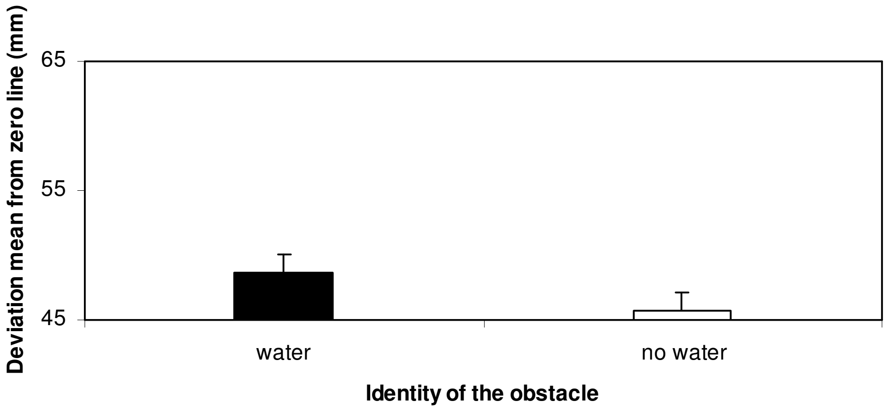

Figure 4. *Maximum deviation means of identity of the obstacle (standard errors indicated). Left bar shows maximum deviation mean of the reach movement when the glass was filled with water, right bar shows maximum deviation mean when the glass contained no water.*

3. Reaction time

The time between the opening of the shutter glasses and the release of the space bar was considered as the third dependent variable. A repeated measures ANOVA showed a significant effect of location of the obstacle [$F(3,9) = 5.717$, $P = 0.018$]. Paired Samples T-test of location of the obstacle showed that the locations LL and R ($p=0.001$), L and R ($p=0.002$), R and RR ($p=0.01$) differed significantly from each other. Reaction times were 21 ms slower when a glass stood at location R compared to location LL (SD=23.61). Reaction times were 28 ms faster when a glass stood at location L compared to location R (SD=33.38). Finally, reaction times were almost 19 ms faster when a glass stood at location RR compared to location R (SD=28.24). No significant effects of identity [$F(1,11) = 2.775$, $P = 0.124$] or interaction effect [$F(3,9) = 1.853$, $P = 0.208$] were found.

Discussion

Most recent studies have suggested that the dorsal stream is responsible for visual guidance during obstacle avoidance. In the present study, we examined the effect of the identity of a glass (filled with or without water) on obstacle avoidance behavior. The aim of our research was to investigate the influence of object identity during obstacle avoidance.

The main manipulation in the current study involved the identity of the obstacle. Results showed that this manipulation influenced the maximum deviation of reach trajectories. A glass filled with water caused the maximum deviation of the reach movement to veer further away from the zero line, compared to a glass without water. This suggests that in some circumstances identity of the obstacle influences reaching behavior. When an obstacle is harmful (or noxious) we want to remove the risk of collision entirely. A full glass of water provides a greater threat, because we do not want to get wet while reaching for something.

Interestingly, identity of the obstacle had no effect on deviation from the zero line at the width of the obstacle. However, movements veered away from the zero line much wider before crossing the glass. This effect declines continuously as the hand approaches the target. This continuously decreasing effect is consistent with a planning/control model of action, in which cognitive and perceptual variables affect how actions are planned but not how they are monitored and controlled on-line. Glover & Dixon (2002) examined how the semantics of word labels affect the planning and control stages of grasping. Subjects were presented with objects on which were printed either the word “LARGE” or “SMALL.” The experiment showed that a semantic effect was present during the early stages of a reaching and grasping movement and decreased over the course of the movement (Glover & Dixon, 2002). It is possible that the identity of the glass could have caused similar reactions, in which the trajectories deviated away from the zero line at a maximum in the early stage of the reach movement, before the effect declined at the width of the glass. We did not find an effect of identity on reaction time. This could be explained by the fact that the releasing of the spacebar is an automatic response to the opening of the glasses and the subjects did not attend to the identity of the glass before releasing the spacebar. There have been no investigations, to our knowledge, directed at the effect of obstacle identity on reaction time.

Results showed that the location of the obstacle had a significant effect on each dependent variable. This means that the position of the glass influenced reach movements in terms of deviation from the zero line, maximum deviation and reaction time. The placement of the glass close to the zero line caused wider reach deviations from the zero line compared to reach movements when a glass was positioned further away. This can be explained by the assumption that an automatic modification in our reach movements ensures us we do not bring our hand within a minimum preferred distance from the glass. (Chapman & Goodale, 2008; Howard & Tipper, 1997; Tresilian, 1998). The effect of location on maximum deviations is also consistent with this idea, as obstacle placement near the zero line caused wider maximum deviations of reach trajectories. The effect of location on reaction time is caused by the level of obstruction from the position of the glass. Position R caused the slowest reaction times, because this position caused more obstruction for the subjects to reach for the wooden block (all subjects reached with their right hands). This is consistent with the suggestion made by Meegan & Tipper (1998) who state that distractors located in the hemispace ipsilateral to the responding hand cause more interference than contralateral distractors. Position R is close to the right side of the zero line, which forced the subjects to alter their movement before releasing the spacebar to assure they did not collide with the glass. Our findings are consistent with results from Tipper, Lortie & Baylis (1992) and Tipper, Howard & Jackson (1997) who suggest that reaction times increase in the presence of nearby placed obstacles during obstacle avoidance.

The present study provides crucial information to the central issue of our research: the involvement of object identity in the act of obstacle avoidance. Based on the present data and the assumption that the ventral stream is responsible for the identification of the properties and identity of objects, we suggest that information from the ventral stream can be used for the visual guidance while avoiding potential obstacles. In accordance with previous work that emphasized ventral stream involvement in obstacle avoidance (Chapman & Goodale, 2008), we believe that the underlying mechanisms of obstacle avoidance depend on complex interactions between dorsal and ventral stream functions. This view is supported by Milner & McIntosh (2003) and Rossetti, Revol, McIntosh, Pisella, Rode, Danckert, Tilikete, Dijkerman, Boisson, Vighetto, Michel & Milner (2005) who state that visuospatial attention during the avoidance of objects might take the form of modulations of neural activity within the dorsal and ventral streams. As we showed that reach trajectories veered further away in case a glass was filled with water, we suggest that the ventral stream is responsible for distinguishing the marginal discrepancy between a full and an empty glass of water, because it is required to react appropriately to more complex stimuli (McIntosh et al., 2004). The dorsal stream alone can not provide for that, because it is specialized in visuo-motor transformations. This view is supported by Schindler and colleagues (2004) who state that the ventral stream must be involved in minimizing the risk of collision entirely if a non-target object is fragile or noxious. The current research contradicts conclusions made by Schindler and colleagues (2004) and Rice and colleagues (2006), as they claimed obstacle avoidance to be a dorsal stream function only. However, an important difference between our study and theirs is that they used cylinders as possible obstacles that did not differed in identity.

Yet, the majority of present research favors dorsal stream function as responsible for the visual guidance we need while avoiding obstacles. It will be worthwhile in future studies to investigate whether the planning/control model of action is also involved in the avoidance of obstacles which differ in identity, as Glover & Dixon (2002) solely found a semantic effect of obstacles. This could provide vital information about the interaction between the ventral stream and other regions of the brain involved in the planning and control of action during obstacle avoidance.

Though some questions still remain unanswered, our research is a relevant endeavour in unraveling the mechanisms involved in obstacle avoidance and the involvement of object identity.

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