The influence of object identity on obstacle avoidance reaching behaviour

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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.

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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 extent) as when they were actually obstructing the movement. Furthermore, hand movements are slowed down when there are nearby obstacles (see for instance Biegstraaten, Sneets, & Brenner, 2003; Chapman & Goodale, 2008; Jackson, Jackson, & Rosicky, 1995; Mon-Williams et al., 2001; Saling, Alberts, Steilmach, & 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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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 non-target 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
participant was allowed to observe the table, target button and (if present) glass. After 800–1200 ms (random to avoid premature movements) a 30 ms beep sound was presented which served as an auditory go-signal. Participants were to press the target button on the other end of the table as fast as possible and then return their finger to the starting position. The shutter glasses closed as soon as the participant pressed the orange button at the starting position, and the experimenter could then change the glass in preparation for the next trial.

Three conditions (no glass (baseline), empty glass and full glass) were tested, with the latter two conditions having glasses at two different locations (8 cm left or right from the virtual midline). The full glass was filled up to 5 mm under the rim with clear tap water. Glasses were changed between trials, when the shutter glasses were closed. The experimenter always put down two glasses, then took away one or both, to prevent differences in sound during the inter-trial interval that could give away the location (or presence) of the obstacle in the upcoming trial. For the same reason, in the case of two subsequent trials of the same condition and location, the glass was first removed and then put back in the manner described above.

Each participant made 45 reaches in total, nine repetitions for every condition–location combination, in randomized order. They were allowed to practice the procedure ten times.

2.4. Data analysis

Trials in which a participant missed the target (0.92%), started moving before the go-signal (1.96%) or failed to respond to the go-signal (0.13%) were excluded from further analysis, as well as four trials due to recording errors (0.52%) and one trial due to an experimental error (0.13%). All raw 3D reaching trajectory recordings were filtered with a 1-dimensional Low pass Butterworth filter (2nd order, cut-off frequency 10 Hz). Velocities at each point along the trajectories were calculated using numerical differentiation. We were interested in the movements towards the target button. The starting point of each movement was defined as the first point at which the velocity of the markers exceeded 5 cm/s. Using the MSI endpoint detection method (see for a detailed description Schot, Brenner, & Smeets, 2010), the endpoint was defined based on two continuous criteria: velocity of markers (lower means more likely to be the endpoint) and the position of the marker on the index finger (closer to the peak measurement on the y-axis means more likely to be the endpoint).

Since we were interested in the movement of the hand, the main analyses were done on the trajectories recorded by the marker on the centre of the hand. To be able to compare complete trajectories, reaching trajectories were resized to 50 sections (interpolating), at equal time intervals. To assess changes in the complete hand movements as a result of the glasses, we projected all movements onto the horizontal plane. We calculated the average horizontal deviation (on the x-axis) of the trajectories in the glass conditions from the average trajectory in the baseline (no glass) condition (see Fig. 2).

The position at which the marker at the centre of the hand passed the centre of the glass on the y-axis for each trial was then interpolated (passing distance). The difference in horizontal deviation from the baseline movement, the average passing distance, and the speed of the hand at this point were compared between empty and full glasses conditions using a location of glass (2) × content of glass (2) repeated measures ANOVA. The same 2 × 2 repeated measures ANOVA was conducted to investigate reaction time (time between the onset of the go-signal and the first measuring point at which the velocity of the markers exceeded 5 cm/s, which was defined as the start of the movement), movement time, peak velocity and time to peak velocity for the marker on the hand. All further comparisons were made with Bonferroni-corrected paired samples t-tests.

3. Results

3.1. Horizontal deviation of the reaching trajectories

Fig. 2 shows a top view of the hand trajectories in trials without glass, a full, or empty glass to the left or right of the midline. The effect of glass content on the complete reaching trajectories in the horizontal plane was assessed by analysing the average horizontal deviation of the paths compared to the baseline condition in which no glass was present. A glass position (2) × glass content (2) repeated measures analysis showed a main effect of glass position (p < .001, F(1,16) = 77.105, $\eta^2_{\text{p}} = 0.828$), reaching trajectories deviated further from the baseline trajectory when the glass was on the right (absolute mean deviation: 28.1 mm 95% CI [22.8, 33.4] SE = 2.51) than when it was on the left (mean 6.08 mm [4.90, 7.27] SE = 0.56). Despite instructions, people
had difficulty keeping their hand straight at the starting position. Therefore, at the start of a trial, the position of the centre of the hand was more to the right than the starting position (mean 51.5 mm [44.8, 58.1] SE = 3.1, t-test (16) = 16.385, p < .001, d = 3.97). This pushes the trajectories rightwards in all glass conditions, thereby probably causing the main effect. Furthermore, there was a main effect of glass content with larger average horizontal deviations when the glass was full than when it was empty: full: mean 17.5 mm [14.6, 20.5] SE = 1.38, empty: mean 16.6 mm [13.9, 19.4] SE = 1.28, p = .447, F(1,16) = 4.632, $\eta^2_p = 0.225$) and an interaction between glass position and glass content (p = .039, F(1,16) = 5.078, $\eta^2_p = 0.241$). Paired samples t-tests showed that there was a difference in deviation from the baseline trajectory in empty compared to full glass conditions when the glass was placed on the right (mean empty: −27.0 mm [21.8, 32.2] SE = 2.45 and full: 29.2 mm [23.6, 34.8] SE = 2.63, t(16) = −2.692, p = .016, d = 0.65, 95% CI [−3.95, −0.47]), but not when it was placed on the left (mean empty: 6.29 mm [5.03, 7.54] SE = 0.59 and full: 5.88 mm [4.46, 7.30] SE = 0.67, t(16) = −0.690, p = .500, d = 0.17, 95% CI [−0.85, 1.66]).

3.2. Passing distance

To clarify how much distance is kept from the potential obstacles, we additionally analysed the average distance between the centre of the hand and the glass at the moment the hand is passing the glass (passing distance), when the glass was empty and full with water (Fig. 3). A glass position (2) × glass content (2) repeated measures analysis showed the same pattern as the analysis on the complete reaching trajectories. There was a main effect of glass position on passing distance (p = 0.001, F(1,16) = 18.835, $\eta^2_p = .541$) (left: mean 113.5 mm 95% CI [108.9, 118.1] SE = 2.16, right: mean 99.5 [93.4, 105.6] SE = 2.87 mm). Also, there was main effect of glass content (full: mean 101.7 mm [102.8, 111.5] SE = 2.06, empty: mean 105.8 mm [101.8, 109.8] SE = 1.89, p = .021, F(1,16) = 6.596, $\eta^2_p = .292$), and an interaction between glass position and glass content (p = .045, F(1,16) = 4.751, $\eta^2_p = .229$). Post-hoc paired-samples t-tests showed that there was a difference in passing distance in empty glass compared to full glass conditions when the glass was placed on the right (mean empty: 97.8 mm [91.7, 103.9] SE = 2.88 and full: 101.1 mm [94.9, 107.4] SE = 2.95, t(16) = −3.273, p = .005, d = 0.79, 95% CI [−5.43, −1.16]), but not when it was placed on the left (mean empty: 113.9 mm [109.4, 118.4] SE = 2.13 and full: 113.2 mm [108.2, 118.1] SE = 2.33, t(16) = 0.644, p = .529 d = 0.16, 95% CI [−1.60, 3.00]). Concluding, when the glass was on the right, the hand trajectories kept a larger distance from the glass in full glass conditions compared to empty glass conditions when passing it.

Additionally, there was no significant effect of glass location or content on passing velocities (location: mean left 176 cm/s [161, 190] SE = 6.77, right 172 cm/s [159, 185] SE = 6.02, p = .174, $\eta^2_p = .112$, content: mean empty 175 cm/s [161, 189] SE = 6.74, full 173 cm/s [160, 185] SE = 5.87 p = .280, $\eta^2_p = 0.072$).

3.3. Reaction times, movement times and peak velocities

To investigate whether the observed differences in hand trajectories are based in motor planning, or are accomplished during online control, we performed 4 additional location of glass (2) × content of glass (2) repeated measures ANOVA’s on reaction time, movement time, peak velocity and time to peak velocity for the marker on the hand. If object identity was incorporated during on-line control, you would expect no effect of glass content on reaction times (but note that participants had 800–1200 ms for observation of the workspace and planning of the movement, which could obscure possible differences in reaction time to the subsequent go-signal). You would however expect differences in movement times and in velocity profiles depending on whether the glass was full or empty.

Our analyses showed no effect of glass content on reaction times (empty 221 ms 95% CI [205, 237], full 223 ms [208, 238], p = .791, $\eta^2_p = 0.005$), no effect of glass position (left 221 ms [206, 235], right 222 ms [205, 239] p = .704, $\eta^2_p = 0.009$) and no interaction (p = .192, $\eta^2_p = 0.104$). Note that although reaction times might be considered short, this is due the fact that we are merely measuring the time between the go-signal and the onset of the reaction. Moreover, participants knew there was a go-signal coming approximately 1 s after the shutter glasses opened, and may have responded relatively fast as a consequence. There was no effect of glass content on peak velocity (empty 213 cm/s [201, 224], full 211 cm/s [201, 222], p = .530, $\eta^2_p = 0.025$, also no effect of glass position (left 214 cm/s [203, 225], right 210 cm/s [199, 221], p = .111, $\eta^2_p = 0.151$) and no interaction (p = .492, $\eta^2_p = 0.030$), time to peak velocity (empty 196 ms [183, 209], full 194 ms [183, 205], p = .354, $\eta^2_p = 0.054$, also no effect of glass position (left 193 ms [180, 206], right 197 ms [185, 209], p = .126, $\eta^2_p = 0.140$) and no interaction (p = .892, $\eta^2_p = 0.001$), or movement times (mean empty 368 ms [342, 393], full 368 ms [345, 391], p = .943, $\eta^2_p < 0.001$), although there was a main effect of position (p = .004, F(1,16) = 11.331, $\eta^2_p = 0.415$ with longer movement times when the glasses were on the right (mean 373 ms [350, 396] vs left: 362 ms [337, 388]) and a trend for an interaction between glass content and position (p = .057, F(1,16) = 4.199, $\eta^2_p = .208$). Additional paired sample t-tests showed no significant difference in movement times in empty glass compared to full glass conditions when the glass was on the left (mean empty 365 ms [337, 392], full 360 ms [336, 385], t(16) = 1.660, p = .116, d = 0.40, 95% CI [−1.23, 10.08]) or when it was on the right (mean empty 371 ms [347, 395], full 376 ms [353, 398], t(16) = −1.142, p = .270, d = 0.28, 95% CI [−13.77, 4.13]). Thus, based on these results we consider it most likely that in this experiment, object identity information was included during the planning or programming of the movement.

4. Discussion

The aim of the current study was to investigate whether the predicted consequences of collision with an obstacle influences reaching trajectories. Predicting the consequences requires recognition of the obstacle, involving processing of non-spatial features. Participants reached towards a target area in the presence of an empty or full glass of water. In concordance with earlier studies (Biegastraten et al., 2003; Chapman & Goodale, 2008; Menger et al., 2012; Mon-Williams et al., 2001; Treisman, 1998), our results show that the position of the obstacle has an effect on reaching trajectories. Trajectories veered away more from glasses placed on the right than from glasses placed on the left. This effect has been reported before, and is probably due to the fact that all reaching movements were made with the right arm and the elbow is protruding on the right (Menger, Van der Stigchel, and Dijkerman 2013). Therefore the risk of collision with glasses placed
on the right is higher, and the reaching trajectories deviate more. Importantly, our results additionally show that reaching trajectories veer away more from filled than from empty glasses, as would be expected if predicted consequences of collision are taken into account in the planning or execution of the movement. However, this additional effect was seen only when glasses were placed on the right of the reaching movement. Since the glasses placed on the left were probably less obstructing than the glasses placed on the right, the risk of collision with glasses placed on the left was generally lower (see also Menger, Dijkerman, et al., 2013; Menger, Van der Stigchel, et al., 2013; Menger et al., 2012). Consequently, whether the left glass was full or empty made less of a difference. However, when glasses were more obstructing (on the right), participants veered away more from their baseline movement than when the glasses were on the left. Additionally, they remained at an even larger distance from the glasses when these were full. Similarly, Menger, Dijkerman, et al. (2013) found that similarity in colour between target and obstacles influenced obstacle avoidance only when the obstacle was relatively obstructing. Possibly, when the obstacles on the left in our study would have been placed nearer to the line between the starting position and the target, there may have been an influence of object identity on the movements. Our results suggest that when there is a high chance of collision with an obstacle, the predicted consequences of collision are taken into account when preparing an arm movement.

In this experiment, the predicted consequences of collision required perceptual recognition of the status of the glass (e.g. full or empty), while the spatial features of empty and filled glasses were the same. In line with current models of action planning and control (Glover, 2004; Milner & Goodale, 2008), our results are consistent with the idea that incorporation of predicted consequences happens before execution of the movement, since glass content did not influence movement times or velocity profiles. Glass content also did not affect reaction times. While this might suggest that the influence of object identity in this experiment occurred after movement initiation (e.g. during on-line control), participants had ample time (800–1200 ms) to prepare their movement before the go-signal. As reaction times were measured as the time between this go-signal and the start of the movement, the 800–1200 ms preparation time may have prevented us from finding differences in the recorded reaction times. Consistent with our finding, there are several other strands of evidence that suggest a role of ventral stream input in visually guided reaching in general and obstacle avoidance specifically (Gentilucci et al., 2001; Hesse, Lane, Aimola, & Schenck, 2012; Himmelbach & Karnath, 2005; Lee & Van Donkelaar, 2002; Menger, Dijkerman, et al., 2013; Milner, Paulignan, Dijkerman, Michel, & Jeannerod, 1999; Rice et al., 2008; Verhagen, Dijkerman, Grol, & Toni, 2008; Verhagen, Dijkerman, Medendorp, & Toni, 2012). For instance, Hesse et al. (2012) showed different directional biases in obstacle avoidance between patients with left or right hemianopia. Reaching trajectories of left hemianopic patients shifted more to the left in response to an obstacle as compared to reaching trajectories of right hemianopic patients. This hemispheric shift is considered to be related to ventral stream processing and is typically seen in tasks requiring conscious visual perception. This suggests that while obstacle avoidance may depend on unconscious processing of the workspace, pathways underlyng conscious visual perception (possibly ventral stream areas) can still influence the (preparation of) avoidance movements. Additionally, impaired obstacle avoidance in optic ataxia recovered when a delay allowed ventral stream processing to be involved (Rice et al., 2008) and pointing errors in optic ataxia patients decreased with increasing delays between target presentation and start of the movement, suggesting a (gradually) increasing influence of ventral stream processing on reaching (Himmelbach & Karnath, 2005; Milner et al., 1999). Also, Jax and Rosenbaum (2007) showed that while dorsal stream information is supposed to decay almost completely within a second (Jax & Rosenbaum, 2005), information about the likelihood of an obstacle being present that was deduced from previous trials influenced reaching movements. Thus, it seems that visual memory of obstacle position, presumably dependent on ventral stream processing, can be used in reaching and obstacle avoidance tasks. In fact, it has been suggested that while online motor control is influenced mainly by object characteristics such as location, size and orientation, object identity features and the context of the situation (such as fragility of objects, or perhaps the consequences of knocking obstacles over) would be incorporated in the preparation of a movement, to construct a motor plan that suits the specific circumstances (Chapman & Goodale, 2008, 2010; Glover, 2004; Milner & Goodale, 2008; Schindler et al., 2004). In concordance with this view, our study suggests that visual obstacle avoidance behaviour depends on interactions between dorsal and ventral stream processing.

The current study showed that non-spatial obstacle identity information that is not related to the reaching target can affect reaching trajectories if there is a high chance of colliding with the obstacle. Processing of non-target objects in the environment is quite relevant. When moving towards a target object, we often have to avoid other objects, such as cups of coffee on a cluttered desk. In some situations, consequences of knocking the non-target object over are more undesirable than in other situations, for example when this object is harmful or fragile. The risk of collision with a non-target object then needs to be minimized (Schindler et al., 2004). Thus depending on the estimated consequences of collision, an appropriate safety margin can be determined to maintain during a movement. In our experiment, this was reflected in a larger deviation from the obstacle when the consequences of collision were worse (e.g. spilling water on the table). The additional deviation we report of obstacle identity on reaching trajectories was limited (on average 3.3 mm) and in fact smaller than the average within-subject variance in deviation (average standard deviation ca. 7–9 mm). This would therefore suggest a rather limited increase in safety margin. However, the consequences of collision with a glass of water are not that dramatic. While knocking over a full glass has worse consequences than knocking over an empty glass, it is not exactly life threatening either. The magnitude of the safety margin may be considerably larger when the consequences of collision are increased. It has been suggested that such a safety margin is related to the extensive multimodal visuotactile integration in the space directly around our body, the peripersonal space (Cooke & Graziano, 2004; Graziano & Cooke, 2006; Sambo, Liang, Cruccu, & Iannetti, 2012). This body part centred peripersonal space possibly acts as a defensive zone, and multimodal predictions are used to determine the desired response to nearby objects and for instance avoid contact with harmful objects. Our results suggest that the distance we keep to potential obstacles in obstacle avoidance behaviour may reflect this safety margin.

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References
