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How obstructing is an obstacle? The influence of starting posture on obstacle avoidance

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ABSTRACT

The introduction of non-target objects into a workspace leads to temporal and spatial adjustments of reaching trajectories towards a target. Currently, there are two different explanations for this phenomenon: the non-target objects are considered as either physical obstacles to which we maintain a preferred distance (see Tresilian, 1998) or as distractors that interfere with movement planning (see Tipper, Howard, & Jackson, 1997). These components are difficult to disentangle, however. Our aim was to determine the unique contribution of the avoidance of a physical obstacle to the adjustments of reaching trajectories. In this study, we manipulate the degree of physical obstruction by non-target objects while keeping the a priori visual layout of the workspace more or less constant. This is achieved by placing participants in different starting postures with respect to the orientation of their limb segments. Participants reach towards and grasp target objects with non-targets present in the workspace in a frontal and a lateral starting posture. In the frontal conditions participants showed larger movements away from the non-target on the ipsilateral side of the workspace than in the lateral conditions. The results provide evidence for the interpretation that non-targets influence the movement trajectory partly because they are 'obstructing'.

1. Introduction

Most times we manipulate things in the presence of other objects. In fact, our workspace is normally cluttered and our visual field crowded. Nonetheless, we are able to direct actions smoothly and effortlessly toward target objects in the presence of non-target objects. How these non-target objects are dealt with is a matter of some debate. One aspect that is, at least, agreed upon is that the introduction of non-target objects into a workspace leads to temporal and spatial adjustment of reach-to-grasp trajectories towards a target (Biegstraaten, Smeets, & Brenner, 2003; Bonfiglioli & Castiello, 1998; Castiello, 1996; C. S. Chapman & Goodale, 2008; Dean & Bruwer, 1994; Howard & Tipper, 1997; Jackson, Jackson, & Rosicky, 1995; Kritikos, Bennett, Dunai, & Castiello, 2000; McIntosh, McClements, Dijkerman, Birchall, & Milner, 2004; Meegan & Tipper, 1998; Mon-Williams, Tresilian, Coppard, & Carson, 2001; Pratt & Abrams, 1994; Rice et al., 2008; Rice et al., 2006; Schindler et al., 2004; Tipper et al., 1997; Tresilian, 1998; Tresilian, Mon-Williams, Coppard, & Carson, 2005; Welsh, 2011). These adjustments are relative to reach and grasp parameters that ordinarily occur when reaching towards objects that are presented alone. The paradigm used to study what aspects of non-targets affect movement trajectories is called obstacle avoidance. Currently, there are two accounts that serve to explain adjustments of reaching trajectories during obstacle avoidance: the non-target objects are considered as physical obstacles to which we plan and maintain a preferred distance (Tresilian, 1998) or as distractors that interfere with movement planning (Tipper et al., 1997).

The *physical obstacle* account describes deviating movements after the introduction of a non-target as the result of the preplanning of an avoidance movement to prevent collision with the non-target. The nervous system modifies the reaching movement in response to the presence of obstacles so as to minimize the likelihood of collision based on a preferred distance of the manipulandum to the obstacle. The modification process itself is ostensibly subtle and precise (Mon-Williams et al., 2001). Evidence in line with this account comes from many studies in which an increase in movement time is observed (Biegstraaten et al., 2003; Jackson et al., 1995; Mon-Williams & McIntosh, 2000; Mon-Williams et al., 2001; Saling, Alberts, Stelmach, & Bloedel, 1998; Tresilian, 1998), suggesting that the movement is slowed down to increase spatial accuracy and avoid potential collisions. These adjustments are not a general response to the presence of non-target objects (Mon-Williams et al., 2001), on the contrary, the effect is specific to the lay-out of the workspace, in that non-target objects only elicit an avoidance response when the preferred distance to them is too small.

According to Tipper and colleagues (Tipper et al., 1997), the spatial adjustments that are observed in response to the introduction of non-target objects are caused by the automatic excitation of direction

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sensitive reaching neurons in area 5 of the posterior parietal cortex and in the motor cortex and their subsequent inhibition. Any overlap between the activations for target and non-target is inhibited and leads to two possible deviating movement trajectories (a movement that veers towards or away from the non-target object) depending on the level of inhibition: when inhibition is strong, because excitation is strong due to a particularly salient non-target, the movement veers away from the non-target. In contrast, when excitation is weak, due to a less salient non-target, inhibition is weak and the movement veers towards the non-target. Such errors in the initial action planning are later corrected online during movement execution so that the hand smoothly ends up at the target. Thus, the nervous system, due to ineffective inhibitory mechanisms that are active during selection of a movement target during movement planning, inadvertently modifies movement planning in response to the presence of non-target objects. Simply put, non-target objects act as distractors when trying to plan a movement to the target. This hypothesis is substantiated by the report that stronger activations in reach-related areas in the parietal cortex are observed when non-target objects were present during reach movements than when they were not present (Chapman et al., 2007). It is important to note that changes to the movement trajectory are ultimately dependent on the strength of distraction by the non-target, which in turn is influenced by the non-targets' salience (Tipper et al., 1997).

The goal of this study was to determine the contribution of obstructional factors to movement adjustments related to the introduction of non-targets. Our manipulation was to change starting posture of a typical avoidance movement. Because reaching not only involves the hand, but also the arm, the orientation of the forearm can determine whether a non-target is an obstacle for the forearm or not. Changing the orientation of the lower arm ought not to influence the distracting effects of a non-target. One key feature of this manipulation therefore is that we can study 'obstructing' effects while keeping the visual lay-out constant.

It is interesting to note that several different starting postures have been used in the obstacle avoidance literature, without it being explicitly manipulated. The right hand is placed either midsaggitally with respect to the trunk (see e.g. Tipper et al., 1997; Castiello, 1996; Kritikos et al., 2000; Chapman & Goodale, 2008) or placed laterally to the trunk (see e.g. Tresilian, 1998; Mon-Williams et al., 2001; Chapman & Goodale, 2010). The fingers on the starting location also differ. This varies between thumb and index finger in gentle opposition (e.g. Castiello, 1996), index finger only (e.g. Chapman & Goodale, 2010), and ulnar side of the hand on the starting location (e.g. Kritikos et al., 2000). In addition, the level of description of those orientations differ; from nominal description (which joints are flexed and extended) to detailed report of angles, to no information at all. The orientations of the major body segments involved in the to-be-performed movements are therefore quite diverse between studies.

It has been shown that starting posture affects reach-to-grasp movements when there are no non-targets present (Hesse & Deubel, 2009; Kritikos, Jackson, & Jackson, 1998; Timmann, Stelmach, & Bloedel, 1996). This is supported by work by Rosenbaum and colleagues (Rosenbaum, Loukopoulos, Meulenbroek, Vaughan, & Engelbrecht, 1995): their model states that starting posture determines, in concert with minimizing energetic requirements and required end posture, the movement that has to be performed. It follows from this that changing starting posture affects the reaching movement. Furthermore, this model has been elaborated to allow for obstacle avoidance (Rosenbaum, Meulenbroek, & Vaughan, 2001). This implies that starting posture, from a modeling perspective, affects avoidance behavior, i.e. the reaching trajectory towards a target object with an intermediate non-target object present which affords a collision.

Naturally, in obstacle avoidance experiments where posture was kept constant, any potential effect of starting posture was negated. However, if with different starting postures one can obtain entirely different results, starting posture becomes relevant: in the most extreme case starting posture could determine whether a non-target object was obstructing or distracting and as such what its effect was on the movement trajectories of participants. It is therefore of interest to study the effect of starting posture in itself for obstacle avoidance, as divergent starting postures may lead to different movement trajectories and therefore to other modifications of those trajectories by either obstacles or distractors.

Our experiment was designed to test two different starting postures; one with the hand frontal (or midsaggitally) to the trunk and one with the hand lateral to the trunk. These postures were similar to the ones reported in earlier studies, for a frontal posture see e.g. Castiello (1996) and for a lateral starting posture see e.g. Tresilian (1998). In both starting postures the starting, non-target, and target locations were kept the same. This way, we can directly compare the effect of starting posture without varying the visual lay-out of the workspace, i.e. there was no visual difference between the non-targets when different starting postures were adopted yet the distance of the manipulandum to the non-target was different between these postures. Non-targets were presented ipsi- and contralaterally of the reaching hand and proximally and distally to the midline.

Reasoning in line with the physical obstacle account we expect differences between ipsi- and contralaterally placed objects, in that ipsilaterally placed non-targets are obstacles and need to be avoided particularly for the frontal posture, while contralaterally placed non-targets are not obstacles and therefore irrelevant to the movement. The hypothesis regarding increased physical obstruction by the non-target when adopting a frontal starting posture follows from the assumption that while a non-target is not a pure obstruction to the hand it may enter more into the 'preferred space' around the lower arm while the hand travels to the target. The distractor interference account would also predict differences between ipsilateral and contralateral non-targets, or distractors, and between different proximities to the midline, but not between different postures. These differences would reflect the failure to inhibit automatic responses to the distractors that differ in 'strength' of attentional capture. One attribute that affects the strength of a distractor is position, where it has been reported that differently positioned distractors cause spatiotemporal adjustments that are specifically tuned to those locations (Tipper et al., 1997). In line with this we expect to find a range of different alterations to movement trajectories that are specific for non-target positions.

2. Methods

2.1. Participants

Twelve (2 men, 10 women) right-handed participants (determined by self-report and confirmed by questionnaire) participated in this study. All participants had normal or corrected to normal vision and were naïve to the purpose of the study. They were instructed to rapidly and smoothly execute a lifting movement as a response time task.

2.2. Materials and design

The participant sat in front of a 122 cm × 61 cm table. On this table there was a virtual workspace of 40 cm × 40 cm. In the workspace 2 elements had fixed locations; the start button and the target button. Both were shifted 3 cm rightwards from the center of the table. The start button was positioned 5 cm from the front edge of the table and the target button was situated 40 cm beyond that. The start button responded to button presses by participants and the target button responded to target objects being lifted from it. The non-targets have variable locations; they were placed at different distances from the midline (the line connecting start and target buttons), at widths of 8 and 12 cm.

Participants wore PLATO LCD goggles (Translucent Technologies, Toronto, Canada), which permitted manipulation of visual feedback and MiniBird magnetic markers (Ascension Technology Corporation, Burlington, USA) which allowed kinematic tracking with a sampling rate of 100 Hz over 3 s. These markers were placed at the tips of participants' right index finger and thumb to accurately measure their x, y, and z positions. These locations have been reported earlier as sites for markers (see e.g. Mon-Williams & McIntosh, 2000) and are considered to be the focus of prehension research (Ansuini, Tognin, Turella, & Castiello, 2007). Care was taken to avoid situations in which the width of the marker itself interfered with the movement. The cables were fixed to the participants as well as to the edge of the table with tape and elastic, so that participants could move their arm without restriction.

Tall cylindrical objects (2.75 cm × 2π × 15 cm) were positioned at several locations. The target object was placed on the target button. The non-target objects were placed at a depth of 20 cm (half-way) from the start button, whereas width was 8 or 12 cm (medial and lateral) to the right or left of the midline. In total, there were thus 4 possible locations where objects could be placed as non-targets: Left-lateral, Left-medial, Right-lateral, and Right-medial. Including the control condition, where no non-target was placed in the workspace, there were thus 5 possible configurations of the workspace.

The starting posture was varied across 4 experimental blocks so that participants sat in a position where their lower arm was diagonal and in a position where their lower arm was in a straight orientation twice (see also Fig. 1). These experimental blocks were pseudo-randomized across groups of 4 participants (ABBA). Great care was taken to assure identical starting postures across the experiment. Participants were placed in line with the midline of the workspace with either their midsaggital line (sternum to navel) or the line between the coracoid process and the biceps brachii tendon. We used individual markings on the floor and workspace to quickly and accurately reorient the participants between conditions.

2.3. Procedure

The experiment consisted of 120 trials, 12 repetitions of each of the 5 configurations discussed above (Section 2.2) for both starting postures. All experimental configurations were presented 6 times in a random order, which resulted in a sequence of 30 trials during a single experimental block.

Each trial started with an empty table and with the participants' hands and arms in the relevant starting posture. Starting posture was controlled using tactile cues along which the fingers had to be placed, markings on the floor to assure the correct position for the chair, trunk and feet, and by the experimenter who kept an eye on the overall disposition of the trunk. During this the participants had visual information of the workspace which was masked when they were ready to begin the trial. The non-target and target were then carefully placed on the table by the experimenter; the non-targets at randomly predetermined locations and the target at a fixed location. Next, the experimenter instructed the computer to open the glasses. Once vision was returned the participant had to wait for an auditory 'go' signal after a random duration between 800 and 1200 ms before starting the movement. This signal also prompted the start of the data collection. The movement task was to reach towards and subsequently lift the target from the table and to place it back immediately. Once the target was lifted data collection ceased and the participant had to return his or her hand to the starting button to impose the masking while the experimenter cleared the table.

2.4. Data processing

All analyses regarding the reaching trajectory were conducted on the x, y, and z data from the marker on the tip of the right index finger, except for the analysis of grip aperture which was performed on the index and thumb marker data taken together. Raw 3D data of each trial were filtered using a dual-pass Butterworth filter (2nd order, 20 Hz cut-off). Velocities and accelerations in each cardinal dimension (x, y, and z) were computed. These were used to define the beginning of the movement (Schot, Brenner, & Smeets, 2010). In this case the movement 'started' when marker position was sufficiently close to the starting location (3 mm), the threshold for marker velocity (5 mm/ms) was exceeded for a sufficient number of samples (50 ms). Per trial this yielded a number of sample candidates for the start of the movement. A continuous function then expressed which of the samples was actually closest to the threshold of e.g. minimal speed:

$$Fv = 1 - \frac{v}{vmin}$$

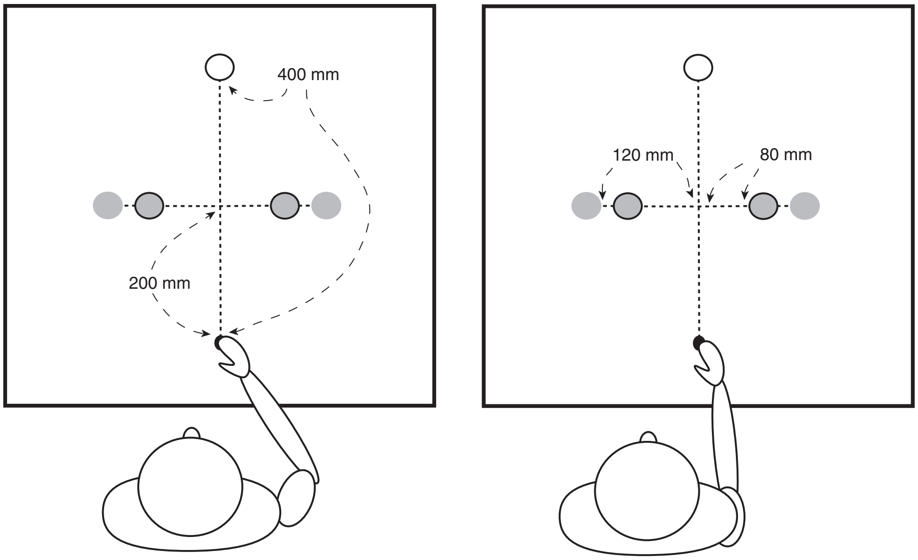

Fig. 1. Top-down view of the experimental setups. The black and white circles separated by the vertical dotted line represent the starting button and the target location, respectively. The 4 gray circles, connected by the horizontal dotted line, are possible locations of non-targets. Gray-ringed circles represent non-targets that are farther away from the midline, while black ringed circles represent non-targets that are closer to the midline. The left panel features the frontal starting posture (lower arm diagonal) and the right panel the lateral starting posture (lower arm straight).

Trials were rejected for the following reasons: the reach never reached the minimum velocity (reported in this section), the reach was initiated before the starting cue was given, the reach did not end within the recording window (3 s), or because of unforeseen recording errors. Less than 10% of trials were rejected (data for 1 participant failed to meet this criterion).

Reach trajectories were normalized to have the same origin in 3D Cartesian coordinate system and the same number of position measurements, viz. 100 position measurements, per axis. In essence, each trial now had 100% movement time, that is, each movement was divided into 99 segments of equal duration. To this end, cubic spline interpolation was used. Trajectories were then averaged across conditions.

As demonstrated by Smeets and Brenner (1995), this type of normalization and subsequent averaging is sensitive to possible errors in determining the movement onset (or offset), that is, averaging across trials could lead to an average that does not resemble individual trials (see Fig. 6 of Smeets & Brenner, 1995). These authors propose position-based averaging instead as a way of dealing with this particular sensitivity. However, because in our experiment we had participants perform reaches to and from locations that were identical across trials and, more importantly, velocity profiles were therefore similar across trials, we argue that both time- and position-based averaging would yield the same results. In addition, we consider that the method that was used to determine the start of the movement (see Section 2.4) circumvented any possible errors in misaligning movement onset between trials, as the starting point of the movement was always within a small sphere with a radius of 3 mm. Taken together, this warrants that within condition comparison and over participant averaging was done on the basis of time-based averaging.

2.5. Dependent measures and analysis

Six measures were used, viz. the spatial measure deviation at passing, deviation at the moment that peak velocity was achieved, and initial direction of the movement, the temporal measure movement- and reaction time, and the grip aperture at the moment the hand passed the non-target were calculated for all trials. Deviation at passing was computed as the distance between the index finger marker and midline in the x-direction (transverse plane) at the moment the y-coordinate at the center of the non-target and index finger marker were identical. Deviation at peak velocity was calculated in much the same way: it was the distance between the index finger marker and the midline in the x-direction (transverse plane) at the moment of peak velocity. Peak velocity itself was computed from a velocity profile (v, t) in which both time and velocity themselves were first averaged as a function of position. This was possible because the distance moved was fairly identical between trials within a condition (see also Smeets & Brenner, 1995). The time it took from movement start to reaching peak velocity was then computed. This information was used to ascertain the deviation in the x-direction at this precise moment. This measure has been used recently by Welsh as a kinematic marker of movement trajectories that reflects preprogrammed or feed-forward processes (Welsh, 2011). Movement time was the time between movement onset and the end of data collection, which coincided with the end of the reach-to-grasp movement. Reaction time was the time between the auditory cue to start the movement and actual movement onset by the participant. The initial direction of the movement was calculated as the angle between the midline and a vector through the (x, y) position of the marker after 15% of the trial's movement time had elapsed. To be more specific, the tangent to the curve was taken at $t = 15\%$ and the angle between this vector and the vertical midline of the workspace (connecting the middle of start button with the middle of the target button) was considered as the initial direction. To illustrate, an angle of $-90°$ would mean a movement only to the right, 0° a movement straight forward and 180° a movement backward. We have chosen to define this measure as an angle instead of a distance because an angle reflects the curvature present in the movement. The curvature, in turn, can also be used to compare different trajectories, a practice that is often used in the study of saccade trajectories where deviation measures are also used (see Van der Stigchel, Meeter, and Theeuwes (2006) for review). Grip aperture was calculated by determining the length of the three dimensional vector between the thumb and index finger markers at the moment the hand passed the non-target, or more precisely, at the moment the y-coordinate at the center of the non-target and index finger marker were identical.

We compared the kinematic parameters of experimental trials for a particular condition with the parameters of the relevant baseline or control condition: for instance, we calculated the difference between the kinematic parameters of a reach from a frontal starting position towards a target with a non-target present on the right (or ipsilateral) side of the workspace and the kinematic parameters of a reach from a frontal starting posture towards a single target. In this case two types of deviation could occur: deviation away and deviation towards (the same holds for curvature). When deviation was away it meant that in a situation where there was a non-target on the ipsilateral side of the participant, the horizontal position of the hand was more to the left when compared to the hand position when there was no non-target present, whereas if the horizontal position of the hand was more to the right than in the situation with no non-target present, then the hand was said to deviate toward the non-target. Conversely, if the hand was more to the right with a contralateral non-target present in the workspace than when there was no non-target present, then the deviation would be labeled as ‘away’, whereas the label ‘towards’ was attributed when the hand was more to the left when the non-target object was on the contralateral side of the workspace with respect to the hand position with only a target present. For the analysis of the results, deviation away was always labeled with a negative sign, while deviation towards was always labeled with a positive sign. This was done via the (conditional) subtraction of the relevant control condition from all experimental conditions. This means that all statistical analyses were performed on difference scores. So, for example, if the deviation at passing difference score for a ipsilateral distractor was -40 mm with a lateral starting posture and -60 mm for a frontal starting posture, then we assumed that with a frontal starting posture participants deviate more away from the non-target. This could have been irrespective of the absolute position of the hand, that is, the trajectories for the control and experimental conditions with the lateral starting postures may have been more to the left in the workspace (characterized by deviation at passing scores of e.g. -10 mm and -50 mm, respectively) than those of the frontal postures (e.g. 30 mm and -30 mm, respectively). The difference score is thus insensitive to absolute differences and reflects the changed behavior in response to non-targets.

For each subject, all the dependent measures were computed for every trial and then averaged for each of the 10 conditions. Where descriptive statistics are presented, “±” always refers to ± standard error of the mean. Statistical comparisons within subjects were made with a repeated measures ANOVA with 3 factors: starting posture (2 levels; frontal, lateral), side (2 levels; left, right), and proximity (2 levels; medial, lateral). All comparisons between experimental conditions were made on the difference score between the experimental conditions and their relevant controls for all dependent measures (as described above). All further comparisons were made with Bonferroni-corrected *t*-tests.

3. Results

Because we subtracted control conditions (no non-target present) from experimental conditions (with non-target) in the subsequent analyses, we first performed a *t*-test to determine whether there was an effect of starting posture on reaching trajectory without non-targets present in the workspace. In control conditions mean deviation at peak velocity was 41.2 mm (±7.6) for the frontal starting postures and 37.6 mm (±5.2) for the lateral starting postures. A paired *t*-test revealed a significant difference ($p < .05$) between these conditions for deviation at peak velocity. Similar tests for initial direction, movement time and reaction time showed no statistically reliable differences. We also performed a paired sample *t*-test on the grip aperture in frontal versus lateral starting postures. Results indicated that there was no significant difference in grip aperture at the moment the hand passed the non-target, $t_{(11)} = 1.66$, $p = .13$, for the different starting postures when no non-targets were present.

This implied that starting posture alone affects reaching trajectory (see also Fig. 2). This is in line with previous results (Kritikos et al., 1998). The timing of the movement and initial direction did not seem to be affected by starting posture. However, in our view, these results warranted a yoked comparison between experimental and their specific control conditions, i.e. conditions with the same starting posture, because the comparison between experimental conditions could otherwise be biased by the unique effect of starting posture possibly obscuring the effect of its interaction with the non-target object in which we are interested.

3.1. Deviation at peak velocity

Because we wanted to compare this measure across conditions we first had to establish that the moment peak velocity reached by participants was equal across conditions, that is, that participants consistently reached their peak velocity after a particular time had elapsed. We ran a repeated measures ANOVA (starting posture [2 levels; lower arm diagonal, lower arm straight], side [2 levels; left, right], proximity [2 levels; medial, lateral]) across the experimental conditions on time to peak velocity. This analysis showed no significant differences. Peak velocity was therefore attained at around the same moment for all conditions. Next we ascertained whether peak velocity was attained at around the same depth across conditions and whether that depth differed from the depth at which the hand passed the obstacle. We performed a repeated measures ANOVA (starting posture [2 levels; lower arm diagonal, lower arm straight], side [2 levels; left, right], proximity [2 levels; medial, lateral]) across the experimental conditions on the depth (y-distance) at which peak velocity was reached. We found no significant differences between conditions. We then compared the mean distance of when peak velocity was reached (M: 150 mm, SD: 11 mm) with the distance at which the hand passed the obstacle (200 mm) and a one-sample *t*-test demonstrated that these distances are significantly different from each other, $t_{(11)} = -12.9$, $p < .0001$. Therefore, peak velocity was consistently reached at roughly the same moment in each movement, at around the same distance which was different from the distance at which the hand passed the obstacle.

We performed a 3 factor repeated measures ANOVA (starting posture [2 levels; lower arm diagonal, lower arm straight], side [2 levels; left, right], proximity [2 levels; medial, lateral]) across the experimental conditions on deviation at peak velocity.

The ANOVA showed that side, $F_{(1,\,11)} = 44.5$, $p < .001$, had a significant effect on the deviation at peak velocity. This suggested that the reaching trajectory at the moment of peak velocity was different when non-target objects were placed ipsilaterally versus contralaterally. In particular, ipsilateral non-targets led to more deviation away from the target than contralateral non-targets (see also Fig. 2, both panels).

In addition, starting posture, $F_{(1,\,11)} = 7.85$, $p < .05$, had a significant effect on the deviation at peak velocity. When seated frontally participants deviated more away than when seated laterally. We found no effect of proximity on deviation at peak velocity. Fig. 2 illustrates the effect of starting posture on movement trajectory.

A trend towards significance ($p = .071$) was revealed for the interaction between side of the non-target and its proximity to the midline.

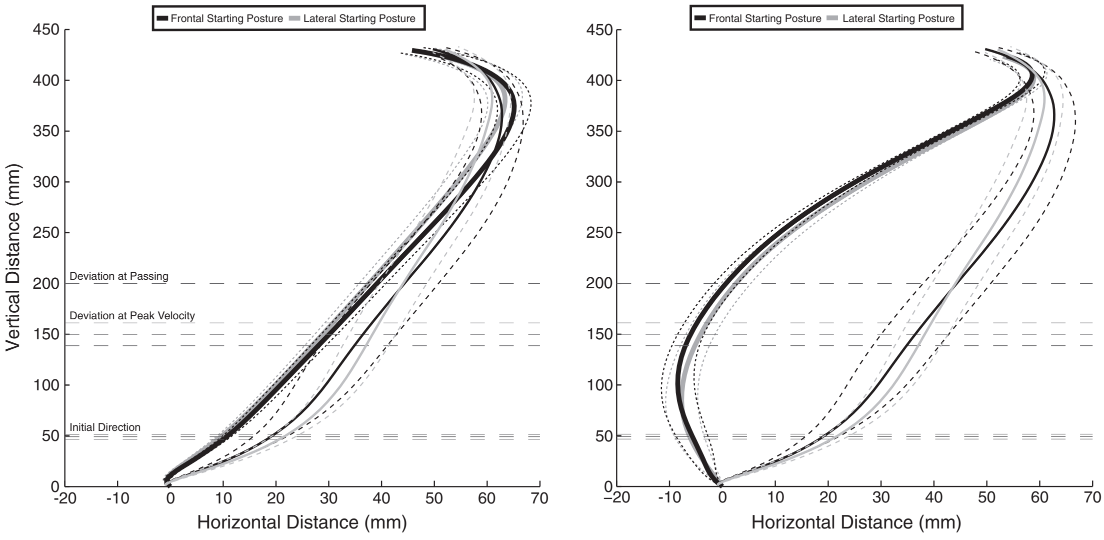

Fig. 2. Movement trajectories for the experimental and control conditions. The thick curves indicate the average movement trajectories across participants as seen from above for contralateral (left panel) and the ipsilateral (right panel) non-target conditions (proximity conditions have been collapsed) with the different starting postures. The thin curves represent the average movement trajectories across participants as seen from above for the control condition with the different starting postures. Horizontal distance from the midline (0) is displayed in mm on the ordinate, vertical distance to target is displayed on abscissa in mm. The solid black lines show the mean movement trajectories with a frontal starting posture and the solid gray lines show the mean movement trajectories with a lateral starting posture. Color-coded dashed lines show standard error of the mean for the mean trajectories across participants for these conditions, with larger dashes for the control conditions and smaller dashes for the experimental conditions. Horizontal gray dashed lines indicate the mean distances at which the measures' initial direction, deviation at peak velocity and deviation at passing were taken for all conditions. Lines at one standard deviation from those means are also provided for the measures' initial direction and deviation at peak velocity. Please note that the sideways translation at the top of the curves is caused by the participants' grip that spans the width of the object. In addition, the markers are on top of the participants' fingers, adding the width of their fingers to the translation. Please note that the curves cannot be compared directly to values in text, because when averaging movement paths over time, the difference of the mean trajectories (the figure) can differ from the mean of the difference between trajectories (values in text).

3.2. Deviation at passing

We repeated this analysis for deviation at passing. A similar pattern was revealed for deviation at passing: again side ($F_{(1,\ 11)} = 49.0$; $p < .001$) and starting posture ($F_{(1,\ 11)} = 7.38$; $p = .022$) had a significant effect on movement trajectory, this time at the point where the hand passes the non-target. The directions of the effect were the same: non-targets on the ipsilateral side caused more deviation away from the non-target, while contralateral non-targets prompted less and more diverse responses; the frontal starting posture yielded larger deviations away and towards than the lateral starting posture. Again no main effect of proximity was found. Neither was any significant interaction effect found.

3.3. Movement time

A 3 factor repeated measures ANOVA (starting posture [2 levels; lower arm diagonal, lower arm straight], side [2 levels; left, right], proximity [2 levels; medial, lateral]) across the experimental conditions on movement time was performed. These results indicated that starting posture, side, and proximity to the midline did not have a significant effect on movement time (p's > .05). No significant interaction effect was found.

3.4. Reaction time

An identical analysis was performed on median reaction times. The results showed that only non-targets' proximity to the midline influenced reaction times, $F_{(1,\ 11)} = 8.69$, $p < .05$. When non-targets were closer to the midline participants reacted slower than when the non-target was placed farther away from the midline. This may be a reflection of increased processing of the non-targets that are closer to the midline relative to those non-targets that were placed more distally, because the former are more likely to collide with the hand when it is transported to the target or because the former elicit greater inhibition. The analysis showed no significant interaction effects.

3.5. Initial direction

A 3 factor repeated measures ANOVA (starting posture [2 levels; lower arm diagonal, lower arm straight], side [2 levels; left, right], proximity [2 levels; medial, lateral]) was performed across the experimental conditions on initial direction. The results show that side, $F_{(1,\ 11)} = 25.8$, $p < .001$, had a significant effect on initial direction. More of interest was the result that starting posture, $F_{(1,\ 11)} = 4.75$, $p = .054$ trended toward significance.

We found a significant interaction effect between the two starting postures and whether the non-target was placed ipsi- or contralaterally, $F_{(1,\ 11)} = 8.36$, $p = .016$. Post-hoc *t*-tests confirmed this effect for frontal vs. lateral starting posture with the non-target on the ipsilateral side, $t_{(11)} = -2.83$, $p = .012$, and demonstrated no effect for frontal vs. lateral starting posture with the non-target on the contralateral side, $t_{(11)} = 0.820$, $p = .42$. Although a trend was found for starting posture, the interaction suggested that this differed in strength for side of the non-targets. That is, the initial direction was more different between postures when non-targets were placed on the ipsilateral side of the workspace. Apparently, with a lateral starting posture the movements with non-targets present on the ipsilateral side of the workspace were centered more around the midline, as indicated by mean initial directions of $-35.9°$ (± 13) and $-38.8°$ (± 12) while with a frontal posture they were more away from the midline, as indicated by mean initial directions of $-53.3°$ (± 12) and $-53.1°$ (± 10). On the contralateral side, however, there were much less pronounced and systematic differences between the two starting postures.

3.6. Grip aperture

We used a 3 factor repeated measures ANOVA (starting posture [2 levels; lower arm diagonal, lower arm straight], side [2 levels; left, right], proximity [2 levels; medial, lateral]) across the experimental conditions to analyze grip aperture at the moment the hand passed the non-target. A similar pattern was revealed for grip aperture as for the reaching trajectory parameters: we found a main effect of starting posture on grip aperture, $F_{(1,\ 11)} = 5.51$, $p < .05$, that is, grip aperture was smaller during movements that started with a frontal posture than in movements that started with a lateral posture when non-targets were present in the workspace. In addition, we found a main effect of side, $F_{(1,\ 11)} = 6.46$, $p < .05$, which indicated that the grip aperture was significantly smaller when non-targets were on the ipsilateral side of the workspace compared with grip apertures in the presence of contralateral non-targets. Again we found no significant effects for the different levels of proximity; in this case grip aperture was not significantly different when the non-target was closer or farther away from the participant. Furthermore, we found a significant interaction effect between the factors starting posture and side for grip aperture at the moment the hand passes the non-target, $F_{(1,\ 11)} = 12.4$, $p < .01$. This indicated that the grip aperture was more different between starting postures when the non-target was on the ipsilateral side of the workspace. Post-hoc *t*-tests confirmed that the grip aperture with an ipsilateral non-target present was smaller during a movement that started from a frontal posture than that of a movement that started from a lateral posture, $t(11) = -3.86$, $p < .01$. Non-targets on the contralateral side did not prompt differentiated grip apertures for the different starting postures.

In the following we will refer to the spatial parameters of the reaching trajectories together as the movement trajectory. Because each of these measures is indicative of a unique and separate moment in the movement trajectory, then, if they are taken together and demonstrating the same effects, it can be assumed that the whole trajectory is affected by an experimental manipulation. On the contrary, any effect that is present for one measure but not for others must be interpreted as a local effect, restricted for instance to the middle of the movement if there were only an effect for e.g. deviation at passing. This could be due to increased or decreased availability of feedback information, for the middle and the beginning of the movement respectively.

4. Discussion

The current study was designed to test the effect of different starting postures on reaching trajectories when non-target objects were present. We introduced non-target objects into participants' workspace at several locations while they had to reach-to-grasp a target object. Participants were seated in one of two starting postures, viz. with the forearm being placed diagonally or straight ahead. We found that the movement trajectories were different when participants had to use a different starting posture. This is not surprising, since movement trajectory planning is thought to be based on calculating the most efficient transformation from a starting posture to an end posture (the ready-to-grip hand near the target), so the same end posture preceded by different starting postures leads to dissimilar transformations, i.e. movements (see (Rosenbaum et al., 2001). What is surprising, however, is the fact that starting posture interacted with non-target object location at the beginning of the movement. Apparently, when objects are on the right side and closer to the reaching hand, the initial movement trajectory deviates more away from a non-target object when a frontal posture is assumed then when a lateral position is adopted. This is in line with Tresilian's account that we keep a preferred distance between our manipulandum and the non-target object, because we want to avoid potential collisions with those objects (Tresilian, 1998; Tresilian et al., 2005). The results we obtained from the analysis of grip aperture seem to subscribe to this idea, in that the grip aperture at the moment the hand passed the non-target was smaller for more 'obstructing' (e.g. ipsilateral) non-targets, which is a behavioral response that seems to be geared towards minimizing the risk of collision with the non-target (Mon-Williams et al., 2001).

In the introduction we mentioned that by varying posture we would be able to make a non-target object more or less of an obstacle while keeping the visual lay-out constant. The response observed when posture was changed was evident: the results suggest that with a lateral starting posture the ipsilateral non-target became less of a physical obstacle. For the first time, we are now able to state that this is the case, because the visual features of the non-target were not changed, because among other things the position and size of the non-target remained the same. Earlier studies that attributed adjusted movement trajectories because of the presence of non-targets to avoiding a physical obstruction varied position of these objects (Tresilian, 1998). In turn, this means that visual features of the non-target are also changed. Since it has been shown that position also influences the distracting effects (Tipper et al., 1997), any changes in movements that were interpreted as a consequence of a physical obstacle could have been due to distracting effects. We show, however, that there is a suitable manipulation that allows for manipulating one of these effects separately from the other. Our results indicate that non-targets' level of obstruction can be modified. Furthermore, the degree of obstruction of a non-target is an important, but not the only, contributor to modifications of the movement trajectory that are made in response to the presence of non-targets in the workspace. Moreover, we have shown that starting posture has an effect on the avoidance movement trajectory and that in itself warrants careful consideration of starting posture when designing experiments on obstacle avoidance.

Nonetheless, it could be argued that changing starting posture changed the layout of the visual field and thereby distracting properties of non-targets. As we did not use a chin rest to stabilize head position and had no fixation point, an ipsilateral non-target object could appear somewhat more to the right in the lateral condition than in the frontal condition, which could result in less distractor interference and in this particular case, less of a movement away from the non-target. Following this rationale, the opposite effect should then be expected on the contralateral side, that is, increased distractor interference from contralateral non-targets resulting in movement trajectories that veer more towards those objects. A single-sample *t*-test was performed on the deviation scores of all contralateral conditions from the control condition for all spatial parameters to check for this possibility. All statistical comparisons were Bonferroni-corrected and indicated no significant departure from '0'. These results do not indicate increased distractor interference, suggesting that varying postures, in this experiment at least, does not change how distractors (could) affect our reaching. Furthermore, we believe that the change in postures did not yield a sufficient change in visual angle to affect the distracting properties of the non-targets.

It has been theorized that non-targets that are not relevant for the movement have less of an effect on the movement than those that are relevant (Tipper et al., 1997). Our results suggest that movement trajectories around non-targets that are closer to the midline do not differ statistically from non-targets that are farther away from the midline. If it is true that by placing non-targets farther away from the midline they become less relevant to the immediate avoidance movement and are therefore less distracting, then we should have found an effect of proximity to the midline. In our experiment the more contralaterally placed non-targets may have been irrelevant to the movement in that they were never distracting or obstructing our participants. This could account for the lack of a main effect of proximity in our data. An additional analysis of a right (ipsilateral) side effect of proximity of the non-targets to the midline could vindicate the argument that spatial adjustments to *relevant* non-targets could indeed be based on distractor interference. However, paired t-tests between the setups with proximal and distal non-targets, all on the ipsilateral side, did not reveal any significant effects for proximity to the midline on our spatial parameters. Thus, this means that when both starting postures were used, proximity to the midline of the ipsilateral non-target did not affect reaching movements. Another explanation could be that the resolution of 'proximity' was too low, that is, the different proximity conditions may have prompted too similar movement responses.

One alternative way of framing our results is by arguing that starting posture biases where attention is allocated. This means that even though we kept the non-target in the same location (a priori visual layout is the same), a non-target could capture different amounts of attention based on the starting posture of the actor. Conceivably, a particular starting posture may elicit a preferred movement plan to the target that passes closer to a non-target than that of another posture. In essence, the non-target then comes closer to the arm, which is why it captures more attention (or: becomes more salient) during movement planning. This would then result in stronger competition during selection-for-action and therefore cause the movement trajectory to veer more away from the non-target. The speculation that prepared actions can be influenced by non-target objects is supported by the premotor theory of attention (Rizzolatti & Craighero, 1998) that states that attention itself derives from the activity of sensorimotor circuits. Indeed, this hypothesis requires a strong and direct coupling between visual attention and premotor activity. Our results support this idea. The degree of obstruction of a non-target therefore influences the amount of attention captured by the non-target.

We conclude that starting posture is a suitable method to manipulate the degree in which a non-target object obstructs movement without changing the degree in which it could visually distract the actor. Our evidence indicates that non-target objects definitely act as physical obstructions to movement. One key factor in this is that an object need not be an obstacle for the hand, while it may be one for the lower arm. Previous studies may have been too focused on the hand in isolation. Any experiment into obstacle avoidance should therefore consider that starting posture also affects reaching trajectories.

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