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RESEARCH NOTE

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The effect of obstacle position on reach-to-grasp movements

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Abstract Numerous everyday tasks require the nervous system to program a prehensile movement towards a target object positioned in a cluttered environment. Adult humans are extremely proficient in avoiding contact with any non-target objects (obstacles) whilst carrying out such movements. A number of recent studies have highlighted the importance of considering the control of reach-to-grasp (prehension) movements in the presence of such obstacles. The current study was constructed with the aim of beginning the task of studying the relative impact on prehension as the position of obstacles is varied within the workspace. The experimental design ensured that the obstacles were positioned within the workspace in locations where they did not interfere physically with the path taken by the hand when no obstacle was present. In all positions, the presence of an obstacle caused the hand to slow down and the maximum grip aperture to decrease. Nonetheless, the effect of the obstacle varied according to its position within the workspace. In the situation where an obstacle was located a small distance to the right of a target object, the obstacle showed a large effect on maximum grip aperture but a relatively small effect on movement time. In contrast, an object positioned in front and to the right of a target object had a large effect on movement speed but a relatively small effect on maximum grip aperture. It was found that the presence of two obstacles caused the system to decrease further the movement speed and maximum grip aperture. The position of the two obstacles dictated the extent to which their presence affected the movement parameters. These results show that the anticipated likelihood of a collision with potential obstacles affects the planning of movement duration and maximum grip aperture in prehension.

Keywords Movement · Planning · Preparation · Obstacle avoidance · Prehension · Human

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Introduction

Reach-to-grasp (prehension) movements require the hand to be transported to an object of interest whilst the fingers are pre-shaped to match the dimensions of the target object (Jeannerod 1988). These two components are tightly coupled in space and time, with alterations to one component causing changes in the other (Haggard and Wing 1995; Paulignan et al. 1991). Numerous studies have explored the manner in which the nervous system controls these components of hand movement when reaching to grasp an isolated object within the workspace. These studies have been successful in revealing some of the underlying mechanisms of manual control in humans and other species. Nevertheless, prehension movements often involve more than reaching to grasp an isolated object. In many situations, a target object is located in close proximity to other non-target objects (we will refer to such objects as “obstacles”). The presence of obstacles in the workspace places additional constraints on the transport of the hand and the formation of the grasp aperture. The skilful adult human will often reach to grasp an object positioned within a cluttered workspace without bringing any part of the body into contact with the obstacles. This achievement may require modifications of the normal reach and/or grasp aperture formation (i.e. the action that occurs in the absence of the obstacles).

A number of studies have shown that hand trajectories are altered in the presence of non-target objects (Howard and Tipper 1997; Jackson et al 1995; Tipper et al. 1997), but remarkably few experiments have been concerned with the issue of strategic obstacle avoidance. One such study has investigated aiming movements when an obstacle is present in the workspace (Dean and Bruwer 1994). Dean and Bruwer have reported that adult participants maintain a minimum distance between their body parts and the obstacle during movement (see also Sabes and Jordan 1997). Tresilian (1998) has studied reach-to-grasp movements in the presence of obstacles in an adult population. In line with the findings of Dean and Bruwer, Tresilian has found that the nervous system acts so as to avoid bringing body parts too close to obstacles within the workspace. Tresilian reports further that the proximity to the obstacles depends upon the speed of movement, with a faster movement being associated with a greater minimum distance from the obstacle. If an obstacle is positioned close to a target, participants respond by decreasing the size of their grasp aperture and slowing down the whole movement (Tresilian 1998). Consistent with this finding, Mon-Williams and McIntosh (2000) have shown that as the distance between two flanking obstacles gets smaller then so does the prehension movement time increase (see also Jackson et al. 1995). This finding is likely to reflect the fact that a limb's trajectory is more controllable and predictable when the movement is slower (Fisk and Goodale 1988).

The existing experiments on obstacle avoidance suggest that reaching movements are preplanned to take potential collisions with obstacles into account. Moreover, the results of these experiments indicate that the system modifies prehensile movement in a subtle and adaptive manner when obstacles are present (Sabes and Jordan 1997; Tresilian 1998). These findings indicate a movement control strategy that takes into account non-target objects and adjusts aspects of movement so as to avoid collision in a manner that is both subtle and precise. It is important to note that our labeling of non-target objects as obstacles reflects our own theoretical bias regarding the issue of why these objects affect prehension. In fact, the question of why these objects affect movement trajectories has been the source of considerable debate (see Castiello 1999a, 1999b; Tresilian 1999). In the current study we were concerned with the empirical question of how prehension is affected by the presence of non-target objects within the workspace. We prefer to interpret our findings in terms of the non-target objects being obstacles, but in the interests of fairness we have outlined a contrasting interpretation, supplied by an anonymous reviewer. In this interpretation, “it is possible that other things could be causing effects on prehension. That is, it is possible that distractors evoke competing responses and that the inhibition of these responses when selecting the target action can also affect behaviour”. Four studies are cited where the reviewer feels that obstacle avoidance alone cannot explain the data (Meegan and Tipper 1999; Tipper et al. 1997, 2000a, 2000b). The reviewer suggests that “the implication that all distractor effects on hand movements are caused by obstacle avoidance cannot be true. Admittedly many of the effects are probably caused by obstacle avoidance, but others are caused by inhibitory mechanisms resolving competition for action”.

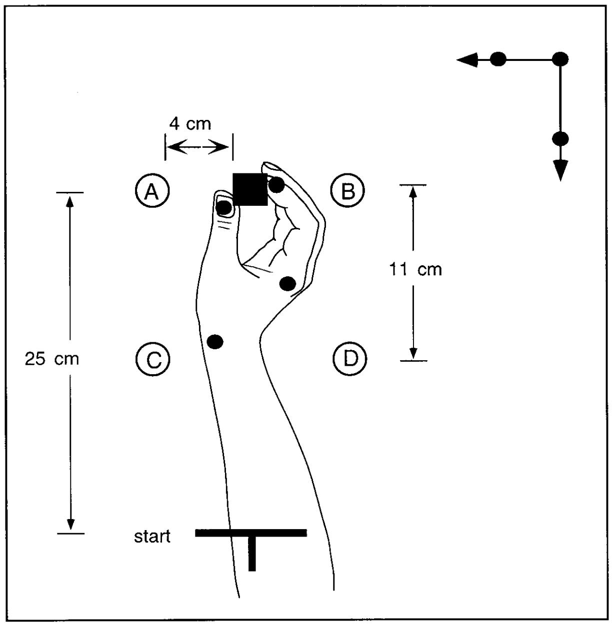


Fig. 1A–D Schematic of the experimental layout from above. Four infrared-emitting diodes (IREDs) were placed on the participant's reaching limb (styloid process of radius, lateral surface of the metacarpophalangeal joint of the index finger, distal phalanx of the index finger and thumb). Participants were asked to reach and grasp the target object (*solid square*) when obstacles (*shaded circle*) were placed either 4 cm to the left (*A*), 4 cm to the right (*B*), 4 cm to the left and 11 cm closer to the participant's edge of the table (*C*), 4 cm to the right and 11 cm closer to the participant's edge of the table (*D*) or with no obstacle in position. The target object had a fixed position 25 cm from the start position along the centreline, which was approximately 12 cm to the right of the participant's midline. The hand was positioned initially with the thumb and index finger touching at the start point defined as the junction of the “T”

The movement control strategies shown by the nervous system in the presence of non-target objects raise the question of how reach-to-grasp movements are modified on the basis of obstacle position within the workspace. The study reported here is an initial step in addressing this issue – it was designed to investigate the obstacle avoidance strategies adopted in response to obstacles located in different locations within the workspace. It is important to note that the obstacles were positioned in the workspace so that they did not interfere physically with the path taken by the hand when no obstacle was present. We were interested specifically in the effect of non-target objects on movement speed and grasp aperture formation – these variables have been shown previously to be affected by the presence of an obstacle close to a target object (Tresilian 1998). The task was simply to reach and pick up a block of wood (Fig. 1) in the presence and absence of non-target objects, which were either positioned some distance in front of the target object or flanked the target block on either side (Fig. 1).

Methods

The target and obstructing objects were arranged on a smooth, flat table surface (Fig. 1). The target object was a square-section block of wood (3×3 cm) 10 cm tall. The two opposite, long sides were painted yellow and the rest black; the yellow sides were defined as the grasping surfaces. The obstacles were unpainted wooden cylinders of 2.5 cm diameter. Two heights of obstacle were used: 10 cm and 5 cm. The obstacles were positioned in one of 17 different configurations: one single short obstacle positioned in locations A to D (see Fig. 1); one tall obstacle positioned in locations A to D; two short obstacles positioned in locations A and D; two tall obstacles positioned in locations A and D; one small obstacle positioned at A and one tall obstacle at position D; one tall obstacle positioned at A and one small obstacle at position D; two short obstacles positioned in locations B and C; two tall obstacles positioned in locations B and C; one small obstacle positioned at B and one tall obstacle at position C; one tall obstacle positioned at B and one small obstacle at position C. Participants carried out ten reach-to-grasp movements for each target configuration, resulting in a total of 170 trials.

Six unpaid adults volunteered to participate in the experiment (three women and three men, aged between 18 and 24 years, mean age 21 years). None of the participants had any history of neurological or ophthalmological abnormality. Participants reached for the target object, which had a fixed position 25 cm from the start position, along the centreline, which was approximately 12 cm to the right of the participant's midline (Fig. 1). The hand was initially positioned with the wrist in a relaxed neutral posture (neither flexed nor extended), with the fingers flexed and the thumb and index finger touching. The point at which the thumb and index finger pads met was at the start point defined as the junction of the "T" in Fig. 1. Participants were instructed to reach out and grasp the target, pick it up and place it on the T. At the beginning of the experiment, the participant was told explicitly to avoid touching the obstacle. The participants were instructed to grasp the target on the yellow surfaces, then the experimenter cued participants to start movement with the verbal signal "Go".

Data acquisition was initiated approx. 1 s before the experimenter's verbal start command. Four infrared-emitting diodes (IREDs) were located on the participant's reaching limb (styloid process of radius, lateral surface of the metacarpophalangeal joint of the index finger, distal phalanx of the index finger and thumb). Positions of the IREDs were recorded by an Optotrak movement-recording system, factory pre-calibrated to a static positional resolution of better than 0.2 mm at 100 Hz (dynamic resolution was not significantly different from this). The raw *X*-, *Y*- and *Z*-coordinates of each IRED were digitally filtered by a dual pass through a 2nd-order Butterworth filter with a cut-off frequency of 20 Hz (equivalent to a 4th-order filter with no phase lag and a cut-off of ≈16 Hz). Following this operation, the tangential speed of the wrist IRED was computed and the onset of the reaching movement was estimated using a standard algorithm. This analysis provided the two primary variables of interest to the study: movement time and maximum grip aperture.

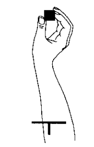
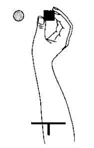
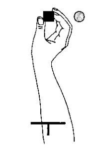
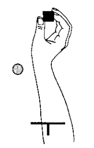
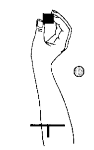
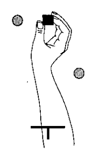
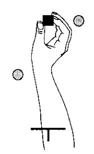
	MOVEMENT TIME	411.47 (ms)
	MAX. GRIP APERTURE	10.55 (cm)
	MAXIMUM SPEED	1275 (mms^{-1})
	MOVEMENT TIME	434.95, f = 0.43
	MAX. GRIP APERTURE	9.46, f = 1.24
	MAXIMUM SPEED	1195, f = 0.57
	MOVEMENT TIME	458.82, f = 0.88
	MAX. GRIP APERTURE	9.19, f = 1.55
	MAXIMUM SPEED	1157, f = 0.85
	MOVEMENT TIME	454.85, f = 0.80
	MAX. GRIP APERTURE	9.62, f = 1.05
	MAXIMUM SPEED	1151, f = 0.89
	MOVEMENT TIME	466.45, f = 1.02
	MAX. GRIP APERTURE	10.08, f = 0.53
	MAXIMUM SPEED	1147, f = 0.92
	MOVEMENT TIME	470.48, f = 1.09
	MAX. GRIP APERTURE	9.02, f = 1.74
	MAXIMUM SPEED	1112, f = 1.17
	MOVEMENT TIME	488.67, f =1.42
	MAX. GRIP APERTURE	8.47, f = 2.37
	MAXIMUM SPEED	1071, f =1.47

Fig. 2 The movement time, maximum grasp aperture and maximum speed data for the various workspace configurations. The *left column* indicates the layout of the workspace, whilst the right column provides the data together with the effect size (*f*) measure relative to the no-obstacle condition

Results

Median values for each dependent measure were derived from the ten experimental trials performed in each condition by each individual participant. Planned comparisons (one-tailed) were performed using a repeated-measures analysis of variance design. In order to assist in the interpretation of the tests of significance, measures of effect size were calculated according to Cohen (1988). The effect size for ANOVA (*f*) is a dimensionless index, which describes the degree of departure from no effect, in other words, the degree to which the phenomenon is manifested. A small effect size is considered by convention to be indicated by an *f* of 0.1, a medium effect size by an *f* of 0.25 and a large effect size by an *f* of 0.4 or more (Cohen 1988).

Initial analyses showed that there were no reliable differences between the tall and short obstacles for any of the variables. The obstacles of different height were considered together, therefore, in the subsequent analyses. This meant that there were six different obstacle configurations of interest (in addition to the no-obstacle condition). Figure 2 provides the movement time, maximum grip aperture and maximum speed for each of these target configurations, together with the relevant effect size (*f*) for the obstacle condition relative to the no-obstacle condition. A reliable effect of obstacle position on move-

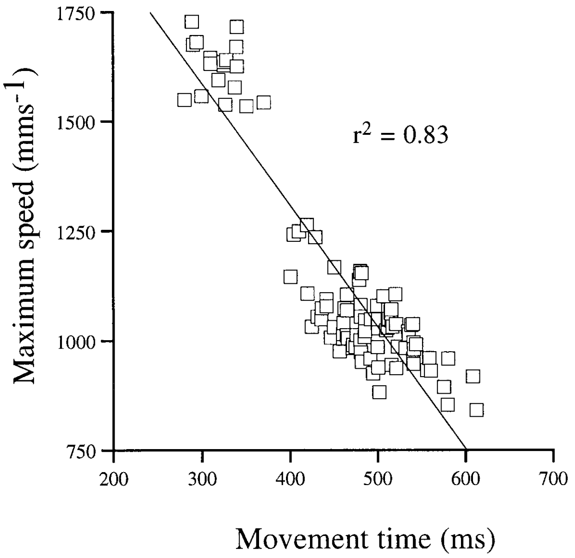


Fig. 3 Movement speed (millimetres per second) plotted against movement time (milliseconds) for all of the participants in all of the conditions

ment time was found in all of the conditions apart from when the obstacle was in position A (obstacle position A: $F_{1, 80}$=3.02, P=0.86; obstacle position B: $F_{1, 80}$=12.29, P<0.05; obstacle position C: $F_{1, 80}$=10.32, P<0.05; obstacle position D: $F_{1, 80}$=16.57, P<0.05; obstacles positioned at A and D: $F_{1, 80}$=22.9, P<0.05; obstacles positioned at B and C: $F_{1, 80}$=39.2, P<0.05). Inspection of the effect sizes provided in Fig. 2 shows that the presence of a single obstacle had a large impact upon movement time in all conditions, although the effect was far less pronounced when the obstacle was at location A.

Figure 2 also provides the maximum grasp apertures for the different conditions together with the relevant effect size (*f*) indicating the impact of the obstacle on grasp aperture relative to the no obstacle condition. A reliable effect of obstacle position on movement time was found in all of the conditions (obstacle position A: $F_{1, 80}$=24.42, P<0.05; obstacle position B: $F_{1, 80}$=38.37, P<0.05; obstacle position C: $F_{1, 80}$=17.79, P<0.05; obstacle position D: $F_{1, 80}$=4.51, P<0.05; obstacles positioned at A and D: $F_{1, 80}$=57.94, P<0.05; obstacles positioned at B and C: $F_{1, 80}$=107.48, P<0.05). Inspection of the effect sizes provided in Fig. 2 shows that the presence of a single obstacle had a large impact upon maximum grip aperture in all conditions although the effect was far less pronounced when the obstacle was at location D.

Finally, the effect of the maximum speed is shown in Fig. 2 together with the relevant effect size (*f*) indicating the impact of the obstacle on maximum speed relative to the no obstacle condition. The pattern of results was identical to that found for movement time (obstacle position A: $F_{1, 80}$=5.22, P<0.05; obstacle position B: $F_{1, 80}$=11.56, P<0.05; obstacle position C: $F_{1, 80}$=12.73, P<0.05; obstacle position D: $F_{1, 80}$=13.66, P<0.05; obstacles positioned at A and D: $F_{1, 80}$=26.45, P<0.05; obstacles positioned at B and C: $F_{1, 80}$=41.57, P<0.05). The correlation between maximum speed and movement time across the conditions is shown in Fig. 3. The high correlation between movement time and maximum speed suggests that the increased movement time was due to the participants slowing down in response to the presence of obstacles.

In order to examine the effect of two obstacles being present against the effect of a single object, the movement time, maximum grip aperture and maximum speed were compared when obstacles were present together in positions A and D compared with when they were present separately in these positions. The results of this analysis showed that the movement time, maximum grip aperture and peak speed were all reliably affected to a greater extent when the two obstacles were present together (movement time: $F_{1, 80}$=5.44, P<0.05; maximum grip aperture: $F_{1, 80}$=35.00, P<0.05; maximum speed: $F_{1, 80}$=54.40, P<0.05). The same analysis was conducted to examine the effect when obstacles were present together in positions B and C compared with when they were present separately in these positions. The results of the analysis showed that the movement time, maximum grip aperture and peak speed were all reliably affected to a greater extent when the two obstacles were present together (movement time: $F_{1, 80}$=16.66, P<0.05; maximum grip aperture: $F_{1, 80}$=54.40, P<0.05; maximum speed: $F_{1, 80}$=17.27, P<0.05).

The final analysis carried out looked at the effect of two obstacles positioned at locations A and D compared with the effect of two obstacles at locations B and C. A reliable difference was found between the two different target locations for movement time, maximum grip aperture and maximum speed (movement time: $F_{1, 23}$=5.44, P<0.05; maximum grip aperture: $F_{1, 23}$=18.98, P<0.05; maximum speed: $F_{1, 23}$=4.25, P<0.05). Inspection of Fig. 2 shows that the effect of the obstacles at locations B and C was greater than when the targets were positioned at A and D.

Discussion

In line with previous findings, the presence of obstacles affected both the speed with which people reached for the target and the maximum grip aperture. Maximum speed of the reach was reduced in the presence of a non-target object in the workspace and this was correlated with an increased movement time (Fig. 3). Similarly, the maximum grip aperture was reduced when an obstacle was present as reported previously (Jackson et al. 1995; Tresilian 1998). The effect on speed tended to be more pronounced when more than one obstacle was present, as predicted from the idea that slowing down is a strategy that allows better control over the limb's trajectory.

The results of the experiment showed clearly that the nervous system modifies the reach to grasp precisely with regard to the environmental layout. In the case where an obstacle was located at position A, the obstacle showed a large effect on maximum grip aperture but a relatively small effect on movement time. In contrast, an object at location D had a large effect on movement speed but a relatively small effect on maximum grip aperture. Furthermore, the presence of two obstacles caused a further increase in movement duration and decrease in maximum grip aperture relative to the effect of a single obstacle in either position. The situation where the two obstacles were located in positions B and C caused a reliably greater effect on movement time and maximum grip aperture than when the obstacles were located at positions A and D.

The picture that emerges from this study is consistent with the idea that the nervous system subtly adapts the reach to grasp movement when obstacles are present in the workspace. In line with previous suggestions, it appears that the system slows down movement and decreases the maximum extent of grip aperture in response to a cluttered workspace. The decreased speed and reduced grip aperture decrease the possibility of the fingers colliding with non-target objects in the workspace. An increase in speed increases the variability of movement and thus raises the possibility of collision. The current findings suggest that the modifications to grip aperture and movement speed are tuned specifically to the layout of the workspace – the changes in movement were specific to obstacle position. In principle, the obstacles in the present study need not have affected the reach-to-grasp movement as none of the positions physically obstructed the movement path taken in the absence of obstacles. Nevertheless, the system clearly operates in a conservative manner, with the planned movement reflecting the anticipated likelihood of collision.

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