Turnaround

To grasp an object one needs to determine suitable positions on its surface for placing the digits and move the digits to those positions. If the object is displaced during a reach-to-grasp movement, the digits’ movements are quickly adjusted. Do these fast adjustments only guide the digits to previously chosen positions on the object’s surface, or is the choice of contact points also constantly reconsidered? Subjects grasped a ball or a cube that sometimes rotated briefly when the digits started moving. The digits always followed the rotation within 115 ms. When the object was a ball, subjects quickly counteracted the initial following response by reconsidering their choice of grasping points so that the digits ended at different positions on the rotated ball’s surface, and the ball was grasped with the preferred orientation of the hand. When the object was a cube, subjects sometimes counteracted the initial following response to grasp the cube by a different pair of sides. This altered choice of grasping points was evident within about 160 ms of rotation onset, which is shorter than regular reaction times.


6.1 Introduction

When you reach out to grasp a glass of water that your friend is offering you, it is unlikely that you can precisely predict every detail of your friend’s movements, so you need to be able to quickly adjust your movements to those of your friend’s. There is abundant evidence that people can indeed adjust various aspects of their movements to new visual information with a latency of only 100-150 ms. People can quickly correct for unexpected perturbations in features of an object that they are reaching or grasping for such as its position (Paulignan et al., 1997; Briere and Proteau, 2011), shape (Eloka and Franz, 2011), size (Paulignan et al., 1997; Hesse and Franz, 2009; van de Kamp et al., 2009) and orientation (Desmurget et al., 1996; Brenner and Smeets, 2009; van Mierlo et al., 2009). They also respond quite quickly to background motion (Brenner and Smeets, 1997) and to changes in visual information about the hand (Saunders and Knill, 2003; Karok and Newport, 2010) or about a cursor that is moved by moving the hand (Brenner and Smeets, 2003). Even the fastest of such responses, the response to a change in target position with a latency of about 100 ms, is well scaled to the size of the perturbation and to the remaining movement time (Oostwoud Wijdenes et al., 2011).

The responses to perturbations generally have a much shorter latency than the time it takes to initiate a movement (Veerman et al., 2008), probably because not all aspects of the movement are reconsidered. Consequently, when confronted with a moving obstacle during a goal-directed movement, people initially follow the obstacle’s motion. If doing so is inappropriate, they correct the response about 50 ms later (Aivar et al., 2008). Similarly, when instructed to respond to a target jump by moving in the opposite direction than the target, people briefly follow the target before moving in the opposite direction (Day and Lyon, 2000). These findings suggest that the initial responses do not arise from new movements being added to the originally planned ones (Flash and Henis, 1991) or from the original movements being
replaced by new ones (Georgopoulos et al., 1981), but are responses of an ‘automatic pilot’ that directs the digits’ movements towards their targets (Pisella et al., 2000). Such an ‘automatic pilot’ being responsible for short latency responses may have interesting consequences for grasping.

We can distinguish between two aspects of grasping (once a target object has been identified): selecting grasping points on the object (Cuijpers et al., 2004; Voudouris et al., 2010) and bringing the digits to the selected points (Smeets and Brenner, 1999). Most of the corrections that have been reported are concerned with controlling movements to selected points. We here examined whether people can also quickly adjust the selection of grasping points after a perturbation. Subjects were asked to reach and grasp either a cube or a ball. In some trials the cube or ball rotated, either in a clockwise or anti-clockwise direction, soon after the subject’s hand started to move. We examined whether the digits followed the selected points on the object’s surface when there was no need to do so (Experiment 1), and whether people could switch to completely different grasping points during the movement if the circumstances made doing so beneficial (Experiment 2).

6.2 Experiment 1

If a cube that one is reaching to grasp suddenly rotates, it will generally be beneficial to rotate ones grip with the cube so that one grasps it at the points on its surface that one had initially selected as being suitable for lifting the cube. However, if a ball rotates, there is no need to adjust the digits’ trajectories because the only thing that changes is that different parts of the ball’s surface are at the originally planned grasping positions in space. These positions would still be appropriate for grasping the ball. The question in the first experiment is whether subjects move their digits to predetermined points on the surface, and thus follow the ball’s motion and rotate their grip in the
same way as they do for a cube, or whether they select new points during the
movement or even neglect the irrelevant rotation of the ball.

6.2.1 Methods

Subjects and apparatus

Ten right-handed subjects (1 man, 9 women; age: 24-30 years) with
normal or corrected-to-normal vision participated voluntarily in the
experiment. They were unaware of the purpose of the study. The experiment
was part of a program that has been approved by the local ethics committee.

Small clusters of three infrared markers were attached to the nails of
the thumb and index finger of the subject’s right hand. The positions of these
markers were measured at 200 Hz with an Optotrak 3020 motion tracking
system (Northern Digital, Waterloo, Ontario, Canada). The marker’s wires
were taped to the subject’s arm so as not to hinder the arm movements.

Subjects stood in front of a table (90 x 52 cm) that was adjusted so
that its surface was at the same height as the subject’s hip. They started each
movement with the tips of their digits aligned laterally with their right
shoulder at a distance of 20 cm from their body. At the starting position, their
arm was resting comfortably on a wooden block (6 cm high; 25 cm wide).
They had to reach and grasp either a ball (6.7 cm diameter; 14.1 g mass) or a
cube (6.7 cm sides; 33.5 g mass), both made of foam. Small nails were pushed
into the bottom of each object, so that they could be placed stably on a magnet
attached to a motor (8 cm high), 30 cm to the left of and 10 cm further from the
body than the starting position. The motor was beneath a wooden board, so
subjects only saw the object on the board.

The motor rotated the object in 33% of the trials. Half of the rotations
were in a clockwise direction and the other half in an anti-clockwise direction.
In 67% of the trials there was no rotation. The rotation occurred about 10 ms
after the onset of the movement was detected (movement threshold of
25 cm/s with all six markers). The 12° rotation took 45 ms. After grasping the object subjects had to place it on top of a cylinder (10 cm high; 2.2 and 3.5 cm axes) that was placed 25 cm to the right of the object’s initial position and 10 cm further away. A scaled top view of the set-up can be seen in figure 6.1.

**Fig 6.1** Schematic top view of the set-up. Subjects saw a cube or ball on a wooden board. They were to grasp this object and place it on a small elliptical cylinder. On some trials the object rotated as soon as their hand started to move.

**Procedure**

Subjects placed their thumb and index finger at the starting position. The experimenter initiated the data collection and a tone generated by the computer indicated that the subject could start moving. Subjects reached for the object, grasped it between thumb and index finger, placed it on the cylinder, and then moved their hand back to the starting position for the next trial. Subjects were informed that after hearing the starting tone they had 5 seconds to fulfil the task. To foster careful, natural grasping movements, we emphasised that the object was to be placed on the tall and narrow cylinder without it falling off. In total there were 120 trials per subject: for each object there were 10 trials for each direction of rotation and 40 trials for the conditions without rotation. The trials were presented in random order.

**Data analysis**

To determine the positions of the fingertips, a calibration trial was done in which a single infrared marker was held between the thumb and index fingertips. The hand-held marker’s position relative to the clusters was
determined, and this relationship was used to calculate the position of each fingertip from the positions of the markers on the clusters during the rest of the experiment.

We determined the velocity of the hand by numerical differentiation of the average of the positions of the two fingertips. A velocity threshold of 0.2 m/s defined the onset of the movement. Grip aperture was defined as the three-dimensional distance between the two fingertips. The moment of the grasp was defined using the MSI method (Schot et al., 2010b): the hand had to be within 6 cm of the centre of the object, its velocity had to be below 0.2 m/s, and grip aperture had to be between 6 and 8 cm. The probability of a moment being the moment of the grasp decreased over time, so the first moment at which all three other criteria were met was considered to be the end of the reach-to-grasp movement. The peak velocity and the maximal grip aperture were determined during the reach-to-grasp movement.

The final grip orientation was the angle of the projection on the horizontal plane of the line connecting the two fingertips at the moment of the grasp. This was considered to represent the chosen grasping points in space. Grasping points on the object’s surface were defined with the help of the average thumb and index finger positions in space at the moment of the grasp when no rotation occurred (averaged over all trials of all subjects for that object). Grasping points were defined with respect to the points on the object’s surface that were at these average positions before any rotation. These points shifted in space when the object rotated. The grasping points on the object’s surface are signed horizontal displacements across the surface, with anti-clockwise displacements being considered positive. We analysed the average displacement of the two digits.

The values of the above-mentioned variables were calculated for each trial and then averaged across the repetitions of each condition by each
The influence of object rotation on these average values was evaluated with repeated measures analyses of variance.

To evaluate the time courses of responses to the perturbations, we determined the rate at which subjects’ grips rotated during the first 250 ms after the onset of the object’s rotation. At the beginning of the movement the fingertips were too close together to reliably determine a grip orientation on the basis of their positions, so we used the average positions of the three markers of each of the two clusters to determine the grip orientation. For judging how fast subjects rotated their grip it is obviously not necessary to accurately reconstruct the positions of the fingertips. For each trial, we calculated the velocity at which the projection of the grip on the horizontal plane was rotating at each moment from when the object started rotating. We then averaged these grip rotation velocities across repetitions for each subject, object and rotation condition. Using these average values, we compared the velocities after clockwise and anti-clockwise rotations for each object and moment from the onset of object rotation with paired t-tests. We considered the first frame on which this difference in grip rotation was significant to be the onset of the response.

6.2.2 Results

General grasping characteristics

Subjects placed their digits at different points on the object after a rotation occurred (figure 6.2a; main effect of rotation: $F_{(2, 18)} = 68, p < 0.001$), especially when grasping the ball (object type by rotation interaction: $F_{(2, 18)} = 6, p < 0.05$). Subjects adopted a $16^\circ$ more clockwise final grip orientation when grasping the ball than when grasping the cube (figure 6.2b; $F_{(1, 9)} = 184, p < 0.001$). The overall final grip orientation depended on the direction of rotation ($F_{(2, 18)} = 16, p < 0.001$), but this was completely due to responses to the rotation of the cube (object type by rotation interaction: $F_{(2, 18)} = 22, p < 0.001$). Maximal
grip aperture was 0.8 cm larger when reaching to grasp the cube than the ball (figure 6.2c; \( F_{(1, 9)} = 55, p < 0.001; \) see Verheij et al., 2012). No significant effects were found for movement time or peak velocity of the hand (overall averages of 503 ms and 8.9 m/s, respectively).

Responses to the rotations

Subjects responded to rotations of the cube and of the ball with latencies of 115 and 130 ms, respectively (figure 6.3). The response to the ball’s rotation was no longer significant 170 ms after the onset of the rotation, whereas the response to the cube’s rotation continued until at least 250 ms after rotation onset.

6.2.3 Discussion

The way people grasp an object depends on its orientation (Cuijpers et al., 2004; Voudouris et al., 2012a). Consequently, our subjects responded to a clockwise rotation of a cube by placing their digits at similar points on its surface (compare red and grey square in figure 6.2a) and therefore different locations in space (red and grey square in figure 6.2b). When the cube rotated in an anti-clockwise direction, the variability in where the digits contacted the
cube’s surface (figure 6.2a) and in the final grip orientation (figure 6.2b) was large because although most of the subjects grasped the cube at the same points on its surface, some subjects occasionally grasped the cube by a different pair of sides. That subjects could switch between pairs of sides shows that the choice of grasping points can be modified during the movement, although the present data do not tell us how quickly.

Fig. 6.3 Velocity at which the grip rotates for the clockwise and anti-clockwise object rotation conditions of experiment 1. Bold parts show the periods for which the velocity of the grip rotation differed significantly between the two rotation conditions. The dashed lines show the average velocities when only considering each subject’s first trial for each kind of rotation. The thick horizontal black line in the lower left of each panel shows the duration of the object’s rotation. Left and right panel are for the cube and ball, respectively. The fast response (present for both objects) persists for the cube, but disappears before a normal reaction time for the ball.

For the ball, subjects also responded to the rotation (figure 6.3b), but ultimately placed their digits on different parts of the surface (circles in figure 6.2a) at about the same locations in space (circles in figure 6.2b; positions even displaced slightly in the direction opposite to the ball’s rotation). Why did our subjects respond to the ball’s rotation at all? An interpretation that would be consistent with earlier studies (Day and Lyon, 2000; Pisella et al., 2000; Aivar et al., 2008; van Mierlo et al., 2009) is that the initial response was an automatic reaction to motion of the selected points on the ball’s surface. This response was aborted after an additional 40 ms, probably because the ball stopped moving after 45 ms and subjects selected new grasping points. The response
did not stop after 40 ms for the cube (figure 6.3a), so it is not only a direct response to the motion. This pattern of responses was already evident on the first rotation trials (dashed lines in figure 6.3), so it cannot be the result of having learnt about our rotations.

6.3 Experiment 2

Since subjects occasionally switched between pairs of sides when grasping the cube, we examined how quickly people can modify their choice of grasping points. Since a cube’s orientation largely determines the pair of sides by which it is grasped (Voudouris et al., 2012a), we selected the initial and final cube orientation in such a way that the most suitable grasping points required a grip rotation in the opposite direction than the direction in which the cube rotated. By doing so, we can dissociate responding to the cube’s motion from reselecting the best way to grasp the cube, and can determine a latency for the latter response.

6.3.1 Methods

Fourteen subjects (2 men, 12 women) who were unaware of the purpose of the study participated in experiment 2. Eleven of them had participated in experiment 1. Except for the details mentioned below, the apparatus, procedure and data analysis were identical to those of experiment 1.

Only the cube was used. It was initially oriented at one of two different angles: 20° or 30° relative to the frontal plane (figure 6.4). These angles were chosen to cover the region for which it is not evident by which pair of sides one can best grasp the object (Wood and Goodale, 2011; Voudouris et al., 2012a), so subjects might choose different pairs of sides on different trials. Consequently, we did not analyse overall changes in grasping points or final grip orientation. In total there were 120 trials per subject: for
each initial cube orientation there were 10 trials for each direction of rotation and 40 trials for the conditions without rotation.

To reliably determine how quickly people change their selection of grasping points, we needed subjects who regularly switched between pairs of sides by which they grasp the cube if it rotates. To detect such switches, we categorized grasps with a final grip orientation of less than 60° as clockwise, and all others as anti-clockwise. If subjects systematically switched between pairs of sides, they would select a final grip orientation in a rotation condition that was uncommon in the no-rotation condition. We therefore examined whether a final grip orientation that was adopted in fewer than 25% of the trials in the no-rotation condition was adopted in more than 50% of the trials in a rotation condition (for the same initial cube orientation). Subjects for whom this was the case were assigned to the switch group, and were asked to participate in an additional, identical session to obtain more switch data. Both these subjects’ data (switch group) and those of the remaining subjects (no-switch group) will be shown.

For analysing the timing of the responses of the no-switch group we averaged each subject’s responses for each rotation condition across the two initial cube orientations. For analysing the switch group’s responses, we determined for which of the two initial cube orientations our subjects showed most switch responses, and averaged the responses to the rotations for that initial cube orientation across the two sessions. Consequently, the presented
responses are based on 40 trials per subject for both groups (20 per direction of rotation). All other variables were averaged over all subjects and orientations.

6.3.2 Results

General grasping characteristics

When the cube rotated, the reach-to-grasp movement was performed in less time (movement times of 395, 390 and 443 ms for the clockwise, anti-clockwise and no-rotation conditions; F(2, 26) = 15, p < 0.001) and with a higher peak velocity (1.5, 1.5 and 1.2 m/s for the clockwise, anti-clockwise and no-rotation conditions; F(2, 26) = 16, p < 0.001). No significant differences were found for maximal grip aperture.

No-switch responses

Seven of the fourteen subjects selected grasping points on the same pair of sides, irrespective of the cube’s orientation or rotation. Their responses to the cube’s rotation were significant 115 ms after the onset of rotation (as in experiment 1; figure 6.5a).

Switch responses

All seven of the remaining subjects switched most frequently for the 20° initial cube orientation. For that initial orientation, six of them adopted an anti-clockwise grip in fewer than 15% of the trials in the no-rotation condition, and in more than 55% of the trials in the clockwise rotation condition. The seventh subject adopted a clockwise grip in 8% of the trials in the no-rotation condition and in 70% of the trials in the anti-clockwise rotation condition. Only two of the subjects also regularly switched between surfaces when the cube was initially oriented at 30°. An initial response in the direction of the cube’s rotation was significant 115 ms after the onset of the rotation (figure 6.5b). The direction of the response had changed by about 160 ms after
rotation onset, and reached significance in the opposite direction 190 ms after the onset of the cube’s rotation.

Fig. 6.5 Velocity at which the grip rotates for the clockwise and anti-clockwise cube rotation conditions of the no-switch group (a), and the 20° initial cube orientation condition of the switch group (b) in experiment 2. Details as in figure 6.3.

6.3.3 Discussion

Subjects again quickly responded to the cube’s rotation. Half of the subjects just followed its rotation (no-switch group). The others frequently selected grasping points on the pair of sides that they would not have ended on if no rotation had occurred (switch group). Importantly, switching to the other pair of sides required a grip rotation in the opposite direction than the direction in which the cube rotated, making it easy to distinguish between the two proposed kinds of responses. The switch group clearly reconsidered their choice of grasping points when the cube rotated, but only after initially responding in the direction of the cube’s rotation. The direction of rotation reversed about 160 ms after the onset of the cube’s rotation (figure 6.5b).

It is important to realize that even within the switch group, the switch responses were not found in all rotation trials. We averaged all trials for which the cube was initially oriented at 20°, without separating trials in which subjects switched from trials in which they did not, because separating the trials might result in selecting trials in which subjects started with a slightly
different grip orientation (which could bias the findings). By averaging across large switch responses and modest no-switch responses in the opposite direction, we underestimate the intensity of the responses, but switch responses dominate because the switch is associated with a 78° change in cube orientation whereas following the rotation of the cube only involves a change of 12°.

Some variability in responses to the rotations (in both experiments) might arise by the selection of grasping points not only depending on the cube configuration after the rotation, but also to some extent on the change itself and experience on previous trials (Kelso et al., 1994). For instance, two subjects of the switch group usually grasped both the 20° and 30° cubes with a clockwise grip, but when the 30° cube rotated in a clockwise direction to 18°, they usually switched to an anti-clockwise grip. The subjects may have overresponded to the cube’s rotation because they did not realize how large it would be. It is unlikely that the 2° difference in cube orientation was critical.

Half the subjects completely changed their grasping points even if a large adjustment of their movement was required to do so, and although they could have grasped the object without doing so. Moreover, they moved faster when the cube rotated (perhaps in response to the visual motion; Smeets and Brenner, 1995), rather than slowing down to gain time to rotate their grip. Thus, altogether, subjects did not appear to be reluctant to change their grip orientation.

6.4 General discussion

We examined whether fast responses to the rotation of an object that one is reaching to grasp are limited to automatic pursuit of the motion of the planned grasping points, or whether the choice of grasping points is also reconsidered. The brief response to the ball’s motion in experiment 1 and the reversal of the direction of the response in experiment 2 indicate that although
the fastest responses follow the motion of the initial grasping points, people also quickly re-evaluate the circumstances and adjust their selection of grasping points.

The initial response latencies that we found are similar to the 100-125 ms latencies of other tasks (Day and Lyon, 2000; Oostwoud Wijdenes et al., 2010) and faster than the 150 ms latencies observed in tasks involving detection of changes in orientation (Brenner and Smeets, 2009; van Mierlo et al., 2009). This is in line with the view that grasping arises from controlling the digits’ movements towards positions, rather than controlling grip formation (Smeets and Brenner, 1999; 2001). The reversal of the responses in experiment 2 had a similar latency to that found in tasks involving the detection of changes in orientation. Note that these responses are still about 45 ms faster than the shortest reaction times to target motion (Smeets and Brenner, 1994), which implies that if responses to perturbations have a shorter latency than the time it takes to initiate a movement because some aspects of the movement are not reconsidered, the selection of grasping points is not such an aspect.

We conclude that people can quickly alter their choice of grasping points during the grasping movement, probably mainly in order to grasp the object with a configuration of their arm and hand that is closer to their preferred configuration (Rosenbaum et al., 2001; Butz et al., 2007; Voudouris et al., 2012b). Such a re-evaluation of the circumstances takes longer than responding directly to visual motion (Aivar et al., 2008). That half the people often switched their grip for a rotation of the cube of only 12° suggests that postural preference is considered important and that switches do not come at a high cost. These findings suggest that even complex aspects of an action, such as selecting grasping points, are constantly evaluated during the ongoing movement.