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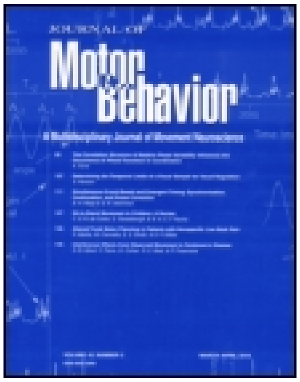
***published in***
Journal of Motor Behavior
2012

***DOI (link to publisher)***
10.1080/00222895.2012.703975

***document version***
Publisher's PDF, also known as Version of record



Journal of Motor Behavior
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/vjmb20

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Version of record first published: 02 Aug 2012.

To cite this article: D. Voudouris, J. B. J. Smeets & E. Brenner (2012): Do Humans Prefer to See Their Grasping Points?, Journal of Motor Behavior, 44:4, 295-304

To link to this article: http://dx.doi.org/10.1080/00222895.2012.703975

Journal of Motor Behavior, Vol. 44, No. 4, 2012


***RESEARCH ARTICLE***

# Do Humans Prefer to See Their Grasping Points?

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**ABSTRACT.** To grasp an object the digits need to be placed at suitable positions on its surface. The selection of such grasping points depends on several factors. Here the authors examined whether being able to see 1 of the selected grasping points is such a factor. Subjects grasped large cylinders or oriented blocks that would normally be grasped with the thumb continuously visible and the final part of the index finger's trajectory occluded by the object in question. An opaque screen that hid the thumb's usual grasping point was used to examine whether individuals would choose a grip that was oriented differently to maintain vision of the thumb's grasping point. A transparent screen was used as a control. Occluding the thumb's grasping point made subjects move more carefully (adopting a larger grip aperture) and choose a slightly different grip orientation. However, the change in grip orientation was much too small to keep the thumb visible. The authors conclude that humans do not particularly aim for visible grasping points.

*Keywords*: grasping points, grip orientation, obstacles, vision

Grasping control has been studied extensively since the pioneering work of Jeannerod (1984). Many of the studies have dealt with how the grasping posture is achieved (e.g., whether by moving the wrist and closing the hand, or by moving the individual digits), rather than with the selection of suitable positions on which the digits will be placed. However, it is evident that it is important for successfully grasping an object that suitable positions on its surface are chosen for placing the digits, irrespectively of how the digits reach those positions. We refer to these positions as grasping points. Which grasping points are suitable depends on the object's shape (Goodale et al., 1994; Lederman & Wing, 2003), mass distribution (Craje, Lukos, Ansuini, Gordon, & Santello, 2011; Kleinholderman, Brenner, Franz, & Smeets, 2007), position (Desmurget & Prablanc, 1997; Paulignan, Frak, Toni, & Jeannerod, 1997; Schot, Brenner, & Smeets, 2010a), orientation (Cuijpers, Smeets, & Brenner, 2004), and on what the individual intends to do with it (Rosenbaum, Vaughan, Barnes, & Jorgensen, 1992). The influence of position may be a result of the posture when making contact with the object being important (Butz, Herbort, & Hoffmann, 2007; Grea, Desmurget, & Prablanc, 2000; Rosenbaum et al., 1992; Schot et al.; Voudouris, Brenner, Schot, & Smeets, 2010). Similarly, the presence of obstacles may influence the choice of grasping points by limiting the range of possible postures (Rosenbaum, Vaughan, Meulenbroek, & Jansen, 2001; Voudouris, Smeets, & Brenner, 2012). In the present study we examined another way in which obstacles may influence the choice of grasping points: by occluding vision of certain parts of the object that is to be grasped.

Obstacles influence various aspects of how individuals execute prehensile movements (Mon-Williams, Tresilian, Coppard, & Carson, 2001). The digits' paths (Chapman, Gallivan, Culham, & Goodale, 2011; Chapman & Goodale, 2008; Tresilian, 1998) and the speed of their movement (Biegstraaten, Smeets, & Brenner, 2003; Saling, Alberts, Stelnach, & Bloedel, 1998) change when there are obstacles close to the target object or between the starting position and the target object. Obstacles also attract individuals' gaze when manipulating an object (Johansson, Westeling, Backstrom, & Flanagan, 2001). Considering that individuals generally look at their grasping points (Brouwer, Franz, & Gegenfurtner, 2009; Brouwer, Franz, Kerzel, & Gegenfurtner, 2005; Johansson et al.; but see Desanghere & Marotta, 2011), obstacles could have an effect on grasping by influencing gaze because forcing individuals to look elsewhere affects how grasping is executed (Schlicht & Schrater, 2007). Moreover, limiting vision affects hand preshaping (Schettino, Adamovich, & Poizner, 2003), though not in all circumstances (Santello, Flanders, & Soechting, 2002). Thus, altogether, obstacles that limit vision of the hand or target object may influence various aspects of grasping.

In this study we concentrated on visibility of the grasping points. Whether the grasping points are occluded influences where subjects fixate when grasping an object, and if the object has a known shape subjects regularly direct their gaze toward the position at which the finger will make contact with the object even if that part of the object is not visible (de Grave, Hesse, Brouwer, & Franz, 2008). In the previously mentioned study, subjects were instructed to place the index finger and thumb at specific grasping points. These grasping points were along the flat objects' thin edges and the object was oriented in the frontal plane, so these grasping points were both visible unless they were intentionally occluded. Consequently, subjects could not influence the visibility of their grasping points. In daily life, objects are often large enough to occlude the digits and are usually placed on horizontal surfaces. Individuals generally grasp objects, such as cups, with the thumb closer to the body than the fingers, and therefore with the thumb's grasping point in view as the thumb moves toward it, while the grasping points of the tips of the fingers are at the far side of the object, and are therefore not visible.

If individuals consider it important to see where they place their digits, or one of the digits, occluding the thumb's usual grasping point may influence the selection of grasping points. To study this, we asked subjects to reach and grasp objects that were either fully visible or partly occluded. In a first experiment we used cylindrical objects (normal

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and ellipsoidal cylinders) for which subjects could choose from a wide range of possible grip orientations. In a second experiment we used a block that was oriented in such a way that subjects had to choose between two orthogonal grip orientations.

If being able to see at least one of the grasping points is considered to be important, we expected subjects to select different grasping points, and thereby a different grip orientation, when the usual grasping point is occluded. Subjects might either choose a grip orientation so that the thumb's grasping point remains visible, or choose a grip that would make the finger's grasping point visible. We anticipated that partly occluding the object would also make subjects grasp more carefully, as reflected by longer movement times and larger grip apertures (Smeets & Brenner, 1999); they would either not adjust their grasping points, and therefore move more carefully because they have less information for performing the task, or adjust their grasping points, and therefore move more carefully because they must grasp in a less comfortable posture.

## EXPERIMENT 1

### Method

#### Subjects and Apparatus

Thirteen right-handed subjects (10 women and 3 men, 23–32 years old) participated voluntarily in this study. All of them had normal or corrected-to-normal vision. None of them knew the precise purpose of the study. The experiment was part of a program that has been approved by the local ethics committee.

Movements of the thumb, index finger, and forehead were recorded at a sampling rate of 250 Hz (resolution 0.1 mm) using an Optotrak 3020 infrared tracking system with two cameras (Northern Digital, Waterloo, Ontario, Canada). Small markers (infrared light emitting diodes) were attached to the nails of the two digits of the right hand and to the center of the forehead using elastic gum. The wires connecting the markers with the computer were taped to the body at several places so that they did not hinder the movements.

Subjects stood in front of a height-adjustable table (60 × 52 cm) wearing liquid-crystal shutter goggles (PLATO, Translucent Technologies, Toronto, Canada) that were only transparent during trial execution so that subjects could not see the placement of the target objects and occluder. The setup is illustrated in Figure 1. The target objects were three 10-cm-tall cylinders. One of them had a circular base (5 cm diameter, 276 g mass, hereafter simply referred to as *cylinder*). The other two had elliptical bases (with principal axes of 4 and 5 cm, and of 6 and 5 cm; hereafter referred to as *elliptical cylinders*). Their masses were 220 and 330 g, respectively. The object was placed 40 cm from the near edge of the table. For the elliptical cylinders, the longer axis could have an angle of −25°, 0°, or 25° relative to the subject's frontal plane.

In some trials, a transparent screen (32 × 20 cm) fixed to a wooden base was placed between the subject and the object at a distance of 27.8 cm from the near edge of the table (transparent condition). In other trials, a wooden board with the same dimensions as the transparent screen was fixed to the wooden base (opaque condition). In the remaining trials there was no screen between the subject and the target object (no-screen condition).

The screen's right edge was 1.5 cm to the right of the midline, so that the left side of the object could only be seen through the screen (if it was transparent). When the opaque screen was present, subjects could not see the left side of the object. They could see the rightmost edge of the object binocularly, and the rest of the right side with the right eye only. To prevent subjects from moving to the right to see a larger part of the target object, we placed a heavy object (75 cm high) to the right of the subjects' hips. This object made it impossible for subjects to move their hips to the right, but they could still move their shoulder and head to the right. We therefore measured movements of the head as well as of the digits. The digits started at the far-left corner of a wooden block that was placed to the right of the subject's midline, about 30 cm from his or her trunk.

#### Procedure

The height of the table was adjusted so that its surface was aligned with the subject's hip, making sure that the subject could not see the object over the screen (when present). The subject's midline was aligned with the center of the object. The experimenter checked that the subject could not see the left part of the object when the opaque screen was present by moving his finger (that was oriented parallel to the screen) across the top of the object until the subject indicated that he or she could see the experimenter's fingertip (without moving his or her head). The subject was instructed to reach and grasp the target object with a precision grip (i.e., between the thumb and index finger), to lift it, to place it back at the same location, and then to move the hand back to the starting position. Subjects were instructed not to start moving before the goggles opened. No further instructions were given. Subjects were free to move as fast as they liked. There was no familiarization procedure before the actual measurement, so subjects only encountered the objects and orientations while performing the task.

There were five blocks of 27 trials, with one trial for each combination of condition (transparent, opaque, no screen), object type (cylinder, small elliptical cylinder, large elliptical cylinder), and object orientation (–25°, 0°, +25°) within each block. The orientation was obviously irrelevant for the cylinder, so this gave us 15 trials for each of the three conditions for this object. We considered the cylinder to be the most important object because there is no intrinsic reason to grasp it in a particular orientation. The elliptical cylinders

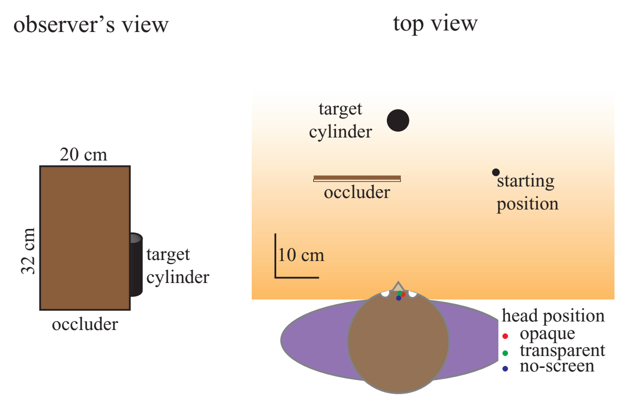


**FIGURE 1.** The setup in the opaque condition. In the top view, averaged positions of the forehead at the moment of the grasp are shown for each condition. (Color figure available online).



imposed additional constraints on the grasping points. They were included to discourage subjects from repeating the same movement throughout the session. Because of the complex relationship between object orientation and grip orientation (Cuijpers et al., 2004), trials with elliptical cylinders were not analyzed, except for illustrating the grip orientations.

### Data Analysis

If a marker was invisible for more than 10 ms during a grasping movement, the trial in question was discarded. If this occurred in more than five trials for the same condition and subject, all data of this subject were discarded. We refer to the average of the positions of the markers on the thumb and index finger as the position of the hand. The velocity of the hand was calculated by numerical differentiation of its position. Grip aperture was the distance (in 3D space) between the markers on the thumb and index finger. The onset of the movement was defined as the first frame in which the velocity of the hand exceeded a threshold of 0.25 m/s. The moment of the grasp was defined using the Multiple Sources of Information method (Schot et al., 2010b) by combining the time from movement onset, the position of the hand in the frontal plane, the hand's velocity, and the grip aperture. The hand had to be within 5 cm of the center of the object, its velocity had to be below 1.25 cm/s, the grip aperture had to be between 5.5 and 10.4 cm, and the probability of a moment being the end of the movement decreased over time. Thus the moment of the grasp was a moment at which the grip orientation was not yet influenced by making contact with the object. Movement time was the time difference between the onset of the movement and the moment of the grasp.

Maximal grip aperture and relative time to maximal grip aperture were determined during the reach-to-grasp movement. Contact asynchrony was defined as the time difference between the minima in the two digits' velocities around the moment of the grasp. This contact asynchrony is therefore determined at the moment of stable contact, slightly later than the moment of the grasp. Grip orientation was the angle of the projection on the horizontal plane of the line connecting the thumb and index finger at the moment of the grasp (Figure 1). The grip orientation was considered to represent the chosen grasping points on the object and is therefore our main measure of interest. We also calculated the grip height, which was the height of the average of the digits' positions at the time of the grasp.

The maximal lateral and maximal forward head positions were the rightmost and most forward positions of the marker on the forehead during the movement, respectively, and they were determined to examine whether subjects tried to obtain more visual information about the partly hidden object during the movement. We also calculated the head's lateral position at the moment of the grasp. The measures of head position are expressed relative to the point on the near edge of the table that was at the subjects' midline at the onset of the experiment.

The values of the previously mentioned dependent variables were calculated for each trial and then averaged across the 15 repetitions of each condition and subject (for the cylinders). The effect of the visual condition on these average values was evaluated with repeated measures analyses of variance. All significant effects ($p < .05$) are mentioned in the Results section. Significant differences between the conditions were examined using the least significant difference post hoc test ($\alpha < .05$). Only the significant differences are reported.

For illustration, average paths of the digits were drawn by resampling the data of each digit's path on each trial in 100 equal steps using linear interpolation (each step corresponding to 1% of the total path length) and then averaging each of the 101 coordinates across the repetitions of each condition and across subjects. It is important to remember when interpreting trajectories that the markers were attached to the nails.

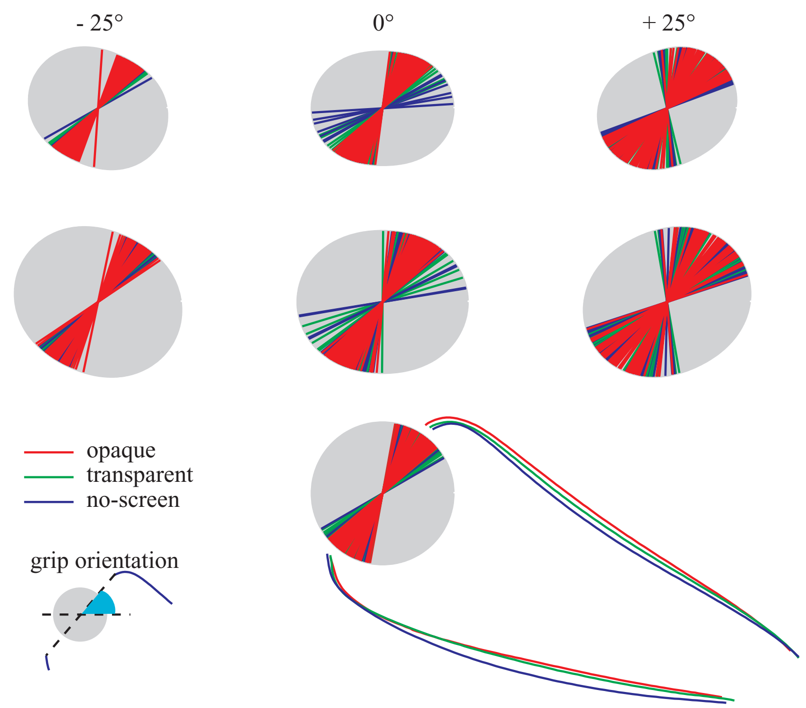


**FIGURE 2.** Grip orientations for all trials of all subjects, for each object type and orientation in Experiment 1. The lines show the orientation of the grip, not the actual placement of the digits, so they all pass through the centers of the objects. Averaged digits' paths are shown for the cylinder. (Color figure available online).

## Results

Based on criteria described previously (see Method), the entire dataset of one subject and a total of seven trials from the remaining 12 subjects' data were discarded. Subjects never knocked down the object or hit the screen. All the objects were grasped with a wide range of grips. Grip orientation for the elliptical objects depended to some extent on the object's orientation, but the grip orientation did not depend on the visual condition to such an extent that it was clearly visible in plots of all the grip orientations (Figure 2). The horizontal projections of the digits' paths toward the cylinder appear to be very similar for the three visual conditions, although it appears as if subjects moved their digits slightly closer to where the screen would have been placed when no screen was present (Figure 2).

The grip orientation when grasping the cylinder was influenced by the visual condition, $F(2, 22) = 16.38$, $p < .001$ (Figure 3). The opaque screen gave rise to the largest angles (more anticlockwise grip; thumb farther to the right), which is consistent with the idea that subjects adjust their grip to be able to see the thumb's grasping point. On average, the difference in grip angle between the opaque and transparent conditions was 2.3°. Such a difference in grip orientation corresponds with a difference in the position on the cylinder's surface of only 1 mm. The small, significant difference in grip orientation between the opaque and the transparent condition must have some other origin than ensuring the visibility of the thumb's grasping point, because subjects grasped with an average angle of 58.1° in the opaque condition, while a grip orientation of more than 95° would be required for the thumb's grasping point to be visible (assuming that the head does not move). Subjects also adopted a 2.5° more clockwise grip orientation in the no-screen condition than in the transparent screen condition, although they could see their thumb through the screen in the transparent condition.

The visual condition also affected the maximal grip aperture, $F(2, 22) = 6.33$, $p < .05$ (Figure 3). Subjects adopted a larger maximal grip aperture when the object was partly occluded than in the transparent and the no-screen condition. The hand's peak velocity was influenced by the visual condition, $F(2, 22) = 4.62$, $p < .05$ (Figure 3): subjects moved with lower peak velocities in the opaque condition. Both of these findings suggest a more careful approach of the object when it was partly occluded.

The maximal lateral head position was affected by the visual condition, $F(2, 22) = 3.49$, $p < .05$ (Figure 3). Subjects moved their forehead farther to the right when the object was partly occluded, but the average rightmost position was only 0.4 cm to the right of the midline. At the moment of the grasp the forehead was to the left of the midline, but there were differences between the conditions: the forehead was 0.6 cm farther to the left in the transparent condition than in

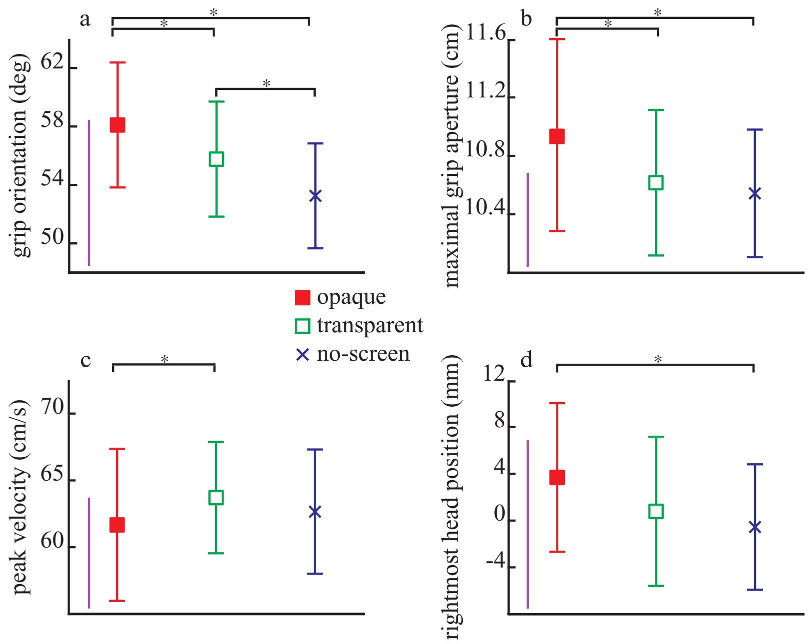


**FIGURE 3.** Significant effects in Experiment 1. Effects of the visual condition on (a) grip orientation, (b) maximal grip aperture, (c) peak velocity, and (d) maximal lateral position of the head. Averages and standard deviations were determined for each of the 15 repetitions performed by each subject. Symbols with error bars show the means of these averages with the associated standard errors. The bars in the lower left corners show the means of the standard deviations, averaged across the three conditions as well as the subjects. Significant differences in post hoc tests are indicated by asterisks. (Color figure available online).



the opaque condition, $F(2, 22) = 7.94$, $p < .005$. The average maximal forward head position was 2 cm in front of the near edge of the table (with no effect of visibility).

There was a significant contact asynchrony: the index finger reached its minimum velocity on average 31 ms before the thumb, irrespective of the visual condition. No effects of visibility were found for the relative time to maximal grip aperture (on average 82%) or grip height (on average 4.5 cm).

## Discussion

We introduced a visual occluder to examine whether subjects tend to select grasping points that are visible. We used a transparent screen to distinguish effects of visibility from effects of the screen as an obstacle. On the majority of the trials the objects were elliptical and varied in orientation to ensure that subjects did not simply repeat their movement across trials. This is confirmed by the plethora of different grip orientations adopted when grasping these objects, as shown in Figure 2. We found that subjects moved more carefully when the object was partly occluded, as reflected by the significantly larger maximal grip apertures and lower peak velocities in the opaque than in the transparent condition. As these measures did not differ between the transparent and no-screen conditions, these effects can be attributed to the visibility of the object.

Grip orientation (i.e., the choice of grasping points) was affected by the visual condition; a more anticlockwise grip was adopted in the opaque condition (Figure 3) This may seem to support the hypothesis that subjects prefer grasping points that are visible. However, the change in grip orientation was much smaller than it would have to be for the thumb's grasping point to be visible. Moreover, considering the average grip orientation of 58.1°, the forehead would have had to move about 3.7 cm to the right of the midline (assuming an interocular distance of 6.5 cm) for the thumb's grasping point to be visible, whereas the forehead only moved 0.4 cm to the right of the midline. Thus, subjects generally did not see the region on the cylinder at which they placed their thumb.

Why then did subjects adopt a more anticlockwise grip in the opaque condition than in the transparent condition? One possibility is that the difference in orientation was found because subjects' head positions at the moment of the grasp were different. The difference of 0.6 cm in head position between the opaque and the transparent conditions could be considered to be equivalent to the object being placed 0.6 cm farther to the left. It has previously been found that a 10 cm (lateral) shift of object location results in a difference in grip orientation of about 19° (Schot et al., 2010a). Thus, the lateral movement of the head could be expected to give rise to a difference in grip orientation of 1.1° between the conditions.

The observed difference of 2.3° suggests that shifting to the right could only account for about half of the difference in grip orientation. A second possible explanation is that the more anticlockwise grip in the opaque condition results from considering the screens as physical obstacles for the forearm. The transparent screen also acts as an obstacle, but it is not unreasonable to give an obstacle more weight when it is more conspicuous and occludes more of the hand.

The finding that subjects moved their head farther to the right in the opaque condition, so that they could see more of the object (and of their moving hand near the object) shows that subjects considered vision of the target object to be important. They may have moved farther to the right to better judge the object's shape and orientation. The movement of the head and the change in grip orientation were too small to bring the grasping points into view.

## EXPERIMENT 2

In the first experiment, subjects would have had to deviate considerably from the grip orientation that they adopted when there was no occluder to see the grasping points when the occluder was present. In a second experiment we reduced the extent to which this is so, by making subjects choose between two different grip orientations (associated with different surfaces of a block-shaped object), under conditions in which they did not show a clear preference for one of the two (Wood & Goodale, 2011). We furthermore moved the screen farther from the object that was to be grasped, to reduce, if not eliminate, its possible role as a physical obstacle.

### Method

Nine right-handed subjects (7 women and 2 men) participated voluntarily in Experiment 2. Two of them had participated in Experiment 1. All of them were naive as to the precise purpose of the study. Except for the details mentioned subsequently, the apparatus, procedure, and data analysis were identical to those of Experiment 1.

Instead of using several cylindrical objects, this time subjects had to reach and grasp a single wooden block (12 cm high; 6 × 6 cm base; 249 g). The block was positioned on a much smaller block of aluminum (3 × 1 × 1 cm) that was firmly attached to the wooden table. The wooden block was placed on the smaller aluminum block to make it important to grasp accurately and thus to choose the optimal grasping points. The wooden block was placed in five different orientations: angles of 0°, 12°, 23°, 34°, or 45° relative to the subject's frontal plane. The orientation of 23° was chosen as the central value because it was expected to be the orientation for which it was least clear by which pair of vertical sides it was most advantageous to grasp the block. We categorized grips as clockwise and anticlockwise by examining whether grip orientation was less or more than 60° from the subject's frontal plane, respectively.

We only included an opaque and a transparent condition. The screen was now placed 23.4 cm from the near edge of the table, so the distance between the screen and the object was 16.6 cm. Again, we placed the screen so that in the opaque condition subjects were able to see about half of the object (with their right eye) without moving their head. The PLATO goggles were not used. A scaled top view of the setup is shown in Figure 4. The moment of the grasp was defined similarly to the first experiment, except that the grip aperture had to be between 5.5 and 11.7 cm.

Subjects started moving after a verbal signal from the experimenter. They were instructed to grasp and lift the object with a precision grip, and place it on the palm of the experimenter, who always held his hand at the same location (next to the object position). We did not ask subjects to place the block back at about the same position, as we did in Experiment 1, because this would become a very demanding task given that the object was initially balanced on a small aluminum block. There were 10 blocks of 10 trials (for a total of 100 trials per subject). Within each block, each kind of trial (two visual conditions; five object orientations) was presented once, in a random order.

### Results

The data of one subject were discarded, as were 18 trials by the remaining subjects. Subjects never hit the screen. In one trial the object was knocked down. This trial was discarded and repeated. We were mainly interested in the side of the object that was chosen for placing the thumb, and in particular which side was chosen when the object was oriented at 23°. To determine this, we analyzed the grip orientation. The distribution of orientations was bimodal (Figure 5a). We split the grip orientations into ones that were less than 60° and ones that were more than 60° (for average paths for each group see Figure 4; the paths were very similar for the two visual conditions). Note that for this object orientation the thumb is only visible at the moment of the grasp if subjects adopt a grip orientation of more than 60°. We compared the fractions of such grips for the transparent and the opaque conditions with paired *t* tests (for each target object orientation). There was no significant effect of the visual condition for any object orientation, suggesting that vision had no effect on the selection of grasping points. An overview of the fraction of clockwise grips as a function of object orientation can be seen in Figure 5b.

Maximal grip aperture was influenced by the visual condition, $F(1, 7) = 11.22$, $p < 0.05$ (Figure 6a). The object's orientation also affected maximal grip aperture, $F(4, 28) = 4.11$, $p < .05$ (Figure 6b): grip aperture was larger when the object was rotated further anticlockwise. This may be due to the edges of the block acting as obstacles (Verheij, Brenner, & Smeets, 2012). The lateral position of the forehead at the moment of the grasp was 1.9 cm farther to the right in the opaque condition than in the transparent condition, $F(1, 7) = 6.94$, $p < .05$, but it was to the left of the midline. In the opaque condition the contact asynchrony was smaller than in the transparent condition, $F(1, 7) = 7.01$, $p < .05$ (Figure 6c).

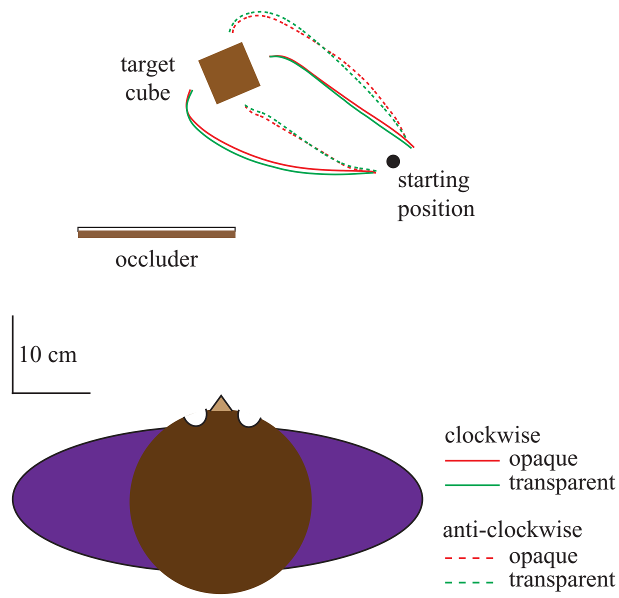


**FIGURE 4.** Schematic top view of the setup in Experiment 2, with the target block oriented at 23°. The digits' average paths when the block was grasped by each of the two different pairs of surfaces are shown for each of the two visual conditions (averaged across subjects). (Color figure available online).

In the transparent condition the finger reached its minimum velocity 11 ms earlier than the thumb (on average), but in the opaque condition this asynchrony disappeared. The object's orientation also affected the contact asynchrony, $F(1, 7) = 7.55, p < .001$ (Figure 6d). No effects of visibility were found for peak velocity (average 61.5 cm/s), or for movement time (average 720 ms). The maximal lateral and forward head position, the relative time to maximal grip aperture (on average 60.2%) and the grip height (on average 4 cm) were not affected by the object's visibility.

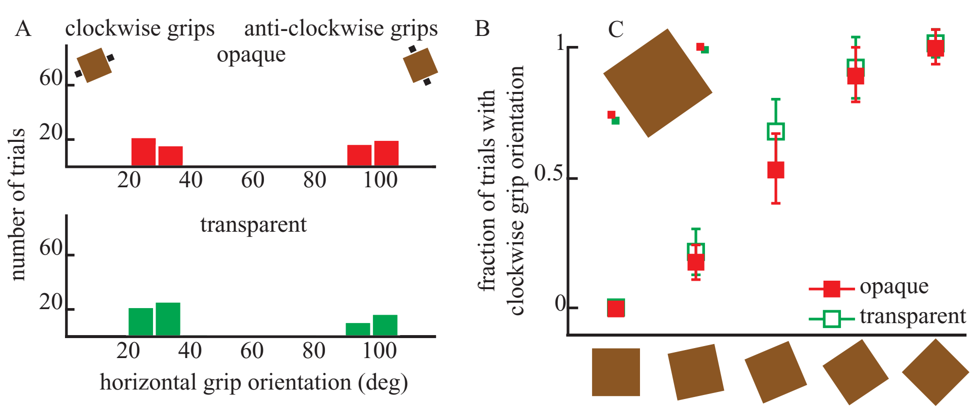


**FIGURE 5.** (A) Bimodal distribution of grip orientations when the object was oriented at 23°. A grip orientation of 0° means that the thumb is to the left of the finger in the frontal plane. Larger angles mean that the grip is further anticlockwise. (B) Fraction of clockwise grips (grip orientation less than 60°) as a function of object orientation. There is only a very slight trend to grasp with a more anticlockwise grip in the opaque condition (filled symbols lower than open symbols) and it was not significant (see text). Error bars represent standard errors of the mean across subjects. Inset (C): Average positions of thumb and index finger (across all subjects) as seen from above when grasping the block oriented at 34°. The depth at which subjects grasped was no different between the two visual conditions (with a trend of having the thumb farther away from a visible position when the occluder was present). (Color figure available online).

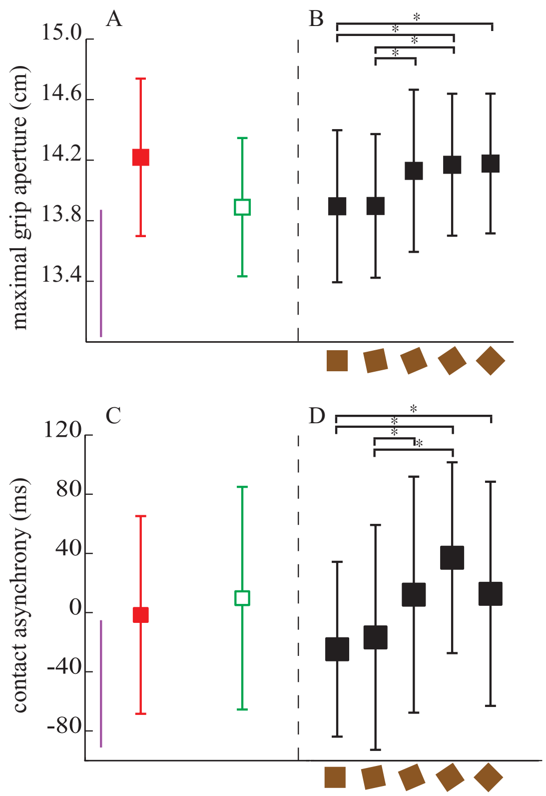


**FIGURE 6.** Significant effects in Experiment 2. Maximal grip aperture as a function of (A) visual condition and (B) object orientation. Contact asynchrony as a function of (C) visual condition and (D) object orientation. Positive values indicate that the index finger arrived first. In panels A and C, filled symbols are for the opaque and open for the transparent condition. Details as in Figure 3. (Color figure available online).

### Discussion

Subjects did not specifically select to place their thumb on the visible side of the block, even in conditions in which they had no clear preference for the sides by which to grasp the block (when vision was not occluded). They did not only grasp the object by the same sides in the two conditions (Figure 5a); the similarities between the selected grasping points for the two visual conditions can also be seen in Figure 5c, where it is obvious that the actual digit placement is also similar. This can also be seen in Figure 4, where it is clear that the digits' paths were very similar. The similarity between the movements cannot be attributed to subjects simply always grasping in the same way, because subjects changed their grip orientation when the object's orientation was changed. Thus, being able to see where the thumb will be placed is evidently not considered to be very important.

In this second experiment we moved the screen farther from the object. The object was a block, forcing subjects to choose between two orthogonal grips. We placed the object on a small base, so that it was more important to approach the object carefully. As in the first experiment, subjects adopted larger grip apertures in the opaque condition. The selection of grasping points was not affected by the visual condition. Neither were movement time, peak velocity, or the maximal lateral or forward head position. In this experiment subjects did not systematically move their head to the right to obtain more visual information about the object or the thumb's grasping point.

In a previous study (Voudouris et al., 2012) we found that obstacles only influenced the selection of grasping points if they were close to where the arm or the digits would be at the moment of the grasp, suggesting that the arm configuration at the moment of the grasp is important for the selection of grasping points. In this study, the position of the screens and of the starting point were chosen so that the screen would not constrain the movement or the placement of the digits on the object. The small difference in grip orientation between the transparent and no-screen conditions in Experiment 1 suggested that the screen may nevertheless have acted as an obstacle for the forearm in that experiment. In Experiment 2 the screen was therefore placed farther from the object.

## GENERAL DISCUSSION

Our main finding is that the selection of grasping points is independent of where visual information is available. As mentioned previously, many factors can influence the choice of grasping points. Our subjects were not even influenced by the visibility of the thumb's grasping point when they had to choose between two grips that were equally likely to be adopted when visibility was not an issue. In Experiment 2, the surface with the thumb's grasping point for the anticlockwise grip was visible, whereas that for the clockwise grip was not. Nevertheless, subjects did not systematically pick the former surface to place their thumb when grasping the object in the opaque condition.

Occluding part of the object did make subjects move more carefully, as judged from increases in grip aperture. A more careful approach is normally found if there is less certainty about reaching precisely the correct position, if it is more important to reach precisely the correct position (Smeets & Brenner, 1999), or if individuals are uncertain about the object's mass distribution (Lukos, Ansuini, & Santello, 2007). Our subjects did consider more visual information to be beneficial, because otherwise they would not have moved their head farther to the right when part of the object was occluded (in the first experiment). However, the effects on grip orientation and head displacement were too small to make the grasping points visible.

Grip orientation is known to depend on the position of the object relative to the shoulder (Schot et al., 2010a; Voudouris et al., 2010). The small effect of occlusion on grip orientation that can be seen in Figure 3a could therefore be a direct consequence of the subjects leaning more to the right to get a better view of the object in the opaque condition. Obviously,

if the objects would have had different, arbitrary, shapes on each trial, subjects would have had to try to obtain more visual information by moving their head, but then the reason for doing so would clearly be to judge the object's shape rather than to see the grasping point in order to move more safely.

It is possible to argue on the basis of the study by de Grave et al. (2008) that individuals find vision of the index finger's grasping point more important than that of the thumb. However, in that study the object was very different and was placed and manipulated differently than in our study. In particular, the objects were very thin and mounted on a vertical surface. In the absence of occluders, this task geometry allowed vision of all possible grasping points for both the index finger and thumb. In our experiment, the objects were at least 10 cm high and standing on a table, which prevents vision of the grasping points at the back. Because individuals normally grasp a standing cylinder, such as a cup, with the thumb's grasping point in view and the fingers' grasping points at the back, we anticipated that the grasping points might change to keep the thumb in view, but of course our results also shows that subjects did not rotate their hands to bring the index finger's grasping points into view. We therefore conclude that although seeing the object is evidently important for grasping, individuals do not find it particularly important to see the grasping points.

## ACKNOWLEDGMENTS

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007–2013 under grant agreement number 214728–2 and from the Alexander S. Onassis Public Benefit Foundation under grant agreement F ZH 016/2011–2012.

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*Received February 24, 2012*
*Revised June 11, 2012*
*Accepted June 14, 2012*