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# The target as an obstacle: Grasping an object at different heights

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ABSTRACT

Humans use a stereotypical movement pattern to grasp a target object. What is the cause of this stereotypical pattern? One of the possible factors is that the target object is considered an obstacle at positions other than the envisioned goal positions for the digits: while each digit aims for a goal position on the target object, they avoid other positions on the target object even if these positions do not obstruct the movement. According to this hypothesis, the maximum grip aperture will be higher if the risk of colliding with the target object is larger. Based on this hypothesis, we made a set of two unique predictions for grasping a vertically oriented cuboid at its sides at different heights. For cuboids of the same height, the maximum grip aperture will be smaller when grasped higher. For cuboids whose height varies with grip height, the maximum grip aperture will be larger when grasped higher. Both predicted relations were experimentally confirmed. This result supports the idea that considering the target object as an obstacle at positions other than the envisioned goal positions for the digits is underlying the stereotypical movement patterns in grasping. The goal positions of the digits thus influence the maximum grip aperture even if the distance between the goal positions on the target object does not change.

## 1. Introduction

When humans reach to grasp a target object, their hand opens wider than the size of the target object (Jeannerod, 1981). For grasping with a precision grip, the maximum distance between the tip of the thumb and the tip of the index finger over the course of the movement is a well-studied parameter: the 'maximum grip aperture' (MGA). It scales with the final distance between the digits on the to be grasped object but is influenced by other aspects as well. The MGA is for instance affected by the location of nearby obstacles (Chapman, Gallivan, Culham, & Goodale, 2011; Jackson, Jackson, & Rosicky, 1995; Mon-Williams, Tresilian, Coppard, & Carson, 2001; Rice et al., 2006; Tresilian, 1998; Tresilian, Mon-Williams, Coppard, & Carson, 2005; Voudouris, Smeets, & Brenner, 2012), target object orientation (Cicerale, Ambron, Lingnau, & Rumiati, 2014; Paulun, Gegenfurtner, Goodale, & Fleming, 2016) and target object shape (Borchers, Verheij, Smeets, & Himmelbach, 2014; Cuijpers, Smeets, & Brenner, 2004; Eloka & Franz, 2011; Hu, Eagleson, & Goodale, 1999; Verheij, Brenner, & Smeets, 2014; Zaal & Bootsma, 1993). Several of the latter authors proposed that the effect of object shape can be explained in terms of the target object being considered an obstacle at positions other than the goal positions for the digits.

A first mention of an obstacle-like explanation of shape effects can be found in the work of Cuijpers et al. (2004). They studied grasping of elliptical cylinders with various sizes and aspect ratio's, and found that when participants grasped elliptical cylinders with various aspect ratios, MGA depended not only on the length of the object at the axis on which it is grasped. They found larger MGAs when grasping along the minor axis, and proposed that this was the result of the protruding parts of the orthogonal major axis acting

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as obstacles.

More recently, Borchers et al. (2014) let participants grasp cuboids along the target object's width and varied the height and depth of the target object independently of its width (the direction of the grasp axis). They found an effect of target object height but not of target object depth on the MGA. They partly explained their findings using the grasping model of Verheij, Brenner, and Smeets (2012) which considers the target object as an obstacle at positions other than the envisioned goal positions for the digits. The risk of hitting the front surface of the target object (which increases with the height of the target object) with a digit is larger than the risk of hitting the side surface (which increases with the depth and height of the target object) and therefore there was no effect of depth on MGA while there was an effect of height. However, they also provided an alternative explanation, namely that humans perceive tall objects as having more volume than shorter objects of exactly the same volume (Raghubir & Krishna, 1999; Wansink & Van Ittersum, 2003), and that MGA might scale with volume.

The alternative explanation for the above-mentioned dependence of MGA on object shape (based on a systematically misperceived volume) was later proven to be unlikely by Verheij et al. (2014). They used five differently shaped target objects with the same maximal width, height, and depth. Verheij et al. (2014) showed that the effect of target object shape on MGA could better be explained by considering the target object as an obstacle at positions other than the envisioned goal positions for the digits, than by the desired precision of the digits' final positions (Smeets & Brenner, 1999), perceived width of the target object (Franz, 2001; Franz, Fahle, Bülthoff, & Gegenfurtner, 2001; Franz, Gegenfurtner, Bülthoff, & Fahle, 2000) or the perceived volume of the target object (Borchers et al., 2014).

Another movement parameter that is influenced by obstacles is the movement time (MT): obstacles in general lead to a longer MT (Biegstraaten, Smeets, & Brenner, 2003; Mon-Williams et al., 2001). Presumably, moving slower reduces the risk of collisions because slow movements can be more precise (Bootsma, Marteniuk, MacKenzie, & Zaal, 1994). For grasping movements, the expected effects of obstacle avoidance on MT are in the same direction as those on MGA.

In this paper, we put the hypothesis of considering the target object as an obstacle at positions other than the goal positions for the digits to a further test in two experiments. If humans indeed have the objective for each digit to avoid collisions between the digit and positions on the target object other than the envisioned goal position, not only characteristics of the target object but also the digit's goal position on the target object is expected to influence MGA. If the digits are placed such that the risk of colliding with the target object at other positions than the goal positions is larger, while the distance between the goal positions is the same, a larger MGA is expected. When grasping a tall target object, parts of the object that the digits pass are more collision-prone than parts of the object beyond the digits' final positions. When grasping a target object from a table, humans usually move their hand initially upwards and then downwards (Verheij, Brenner, & Smeets, 2013), so the digits pass the surface area above the digits' contact positions. Therefore, the collision-prone area of the target object's surface will decrease when grasping the target at a higher position, and a decrease in MGA is expected.

We will test the effect of the collision-prone area by varying the height of the digits' goal positions when grasping a tall cuboid in Experiment 1. To determine whether an effect of the digits' goal positions on MGA in Experiment 1 is indeed caused by a change in collision risk and not merely by an inevitable change of the movement trajectories as a result of changing the digits' goal positions we conducted a control experiment (Experiment 2) in which the change in the digits' goal positions was exactly the same as in Experiment 1, but now designed to let the collision risk increase with grasping height. We achieved this by letting participants grasp cuboids of varying height near the top. Because the part of the cuboid above the digits' final positions acting as an obstacle is absent, the collision-prone area does not depend on cuboid height, but there is more target object surface area to be avoided (below the goal positions) for higher target objects, so the overall collision risk should increase with grasping height. In sum, we predict a decrease in MGA with the height of the digits' goal positions in Experiment 1 due to a smaller collision-prone area and an increase in MGA with the height of the digits' goal positions in Experiment 2 due to a larger surface area that has to be avoided. As one can also deal with increasing risks by slowing down the movement, we predict a similar pattern of results for MT: it will decrease with increasing grasping height in Experiment 1, but increase with grasping height in Experiment 2.

## 2. Methods

### 2.1. Participants

12 naive right-handed participants (7 females, 5 males) took part in both experiments, ranging in age from 24 to 39 years in Experiment 1 and from 25 to 39 years in Experiment 2. Two Participants participated in both experiments. The study was part of a program that was approved by the local ethics committee. Participants signed an informed consent form before participating.

### 2.2. Experimental setup and procedure

Participants sat on a chair without armrests. Approximately 20 cm to the right of the right side of their trunk and approximately 10 cm in front of their trunk a starting location was marked on a table (Fig. 1). At the start of each trial, their hand rested on the table with their index finger and thumb touching each other at the starting location. A cuboid was placed 40 cm in front of the starting location and was oriented such that an imaginary line from the starting location to the cuboid's position would be perpendicular to the cuboid's front surface. Thus the starting location and the cuboid were both located to the right of the participants' body midline.

The cuboid consisted of up to five equally sized two-by-two Duplo bricks (the construction toy produced by the LEGO Group) stacked on top of each other, resulting in a cuboid height of up to 96.0 mm (without studs, 100.8 mm with studs) and a width and