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Effects of object shape on the visual guidance of action

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ABSTRACT

Little is known of how visual coding of the shape of an object affects grasping movements. We addressed this issue by investigating the influence of shape perturbations on grasping. Twenty-six participants grasped a disc or a bar that were chosen such that they could in principle be grasped with identical movements (i.e., relevant sizes were identical such that the final grips consisted of identical separations of the fingers and no parts of the objects constituted obstacles for the movement). Nevertheless, participants took object shape into account and grasped the bar with a larger maximum grip aperture and a different hand angle than the disc. In 20% of the trials, the object changed its shape from bar to disc or vice versa early or late during the movement. If there was enough time (early perturbations), grasps were often adapted in flight to the new shape. These results show that the motor system takes into account even small and seemingly irrelevant changes of object shape and adapts the movement in a fine-grained manner. Although this adaptation might seem computationally expensive, we presume that its benefits (e.g., a more comfortable and more accurate movement) outweigh the costs.

1. Introduction

Humans are able to grasp objects of arbitrary shape with great precision. To do so, information about intrinsic object features, such as absolute size, shape and colour of the object, as well as extrinsic information such as distance and orientation in the environment, need to be transformed in order to develop a motor plan to execute the movement (Jeannerod, 1981, 1988; Pardhan & Gonzalez-Alvarez, 2005). This study addresses the issue of how visual input is used to control grasping movements. Particularly, we investigated whether the shape of an object influences online control of grasping movements.

Most researchers agree that vision for perception transforms visual input in a holistic manner, preserving the relations between object parts. But what about vision used to interact with our environment, especially vision used to grasp objects? Ganel and Goodale (2003) argue that vision for action transforms visual input in a analytic manner, only taking into account the object dimension most relevant for the movement, while ignoring other object dimensions. They especially claim that only the most relevant dimension is processed rather than the entire shape of the object.

In order to test this hypothesis, we made use of a perturbation paradigm. We instructed participants to grasp two different objects, either a bar or a disc. Length of the bar and diameter of the disc were identical. In some trials, object shape changed from bar to disc, or vice versa, during the movement. These trials are hereafter referred to as perturbation trials. We measured the maximum grip aperture (MGA), a well studied parameter to quantify the grasp (Jeannerod, 1981), which scales linearly with the object size with a slope of approximately 0.82 (Smeets & Brenner, 1999). We also determined the angle θ, describing the orientation of finger and thumb (Fig. 1) at the time when the object was touched. We will hereafter refer to θ as the final hand orientation.

If processing of grasping movements is oblivious to the relation between object dimensions, MGA and the final hand orientation should be similar for both bars and discs. Furthermore, changes of object shape during the grasping movement should neither have an effect on MGA, nor on the final hand orientation. On the other hand, if grasping movements are computed such that relations between object dimensions are taken into account, MGA and the final hand orientation may vary. If they vary depending on the object form, introduction of a shape perturbation during the movement might lead to an adaptation of MGA and the final hand orientation in response to the new object form. This would shed more light on how visual information about the shape of an object is used to control grasping movements.

2. Methods

2.1. Participants

Twenty-six undergraduate and graduate students of the University of Giessen (mean age = 23, SD = 3) participated in the

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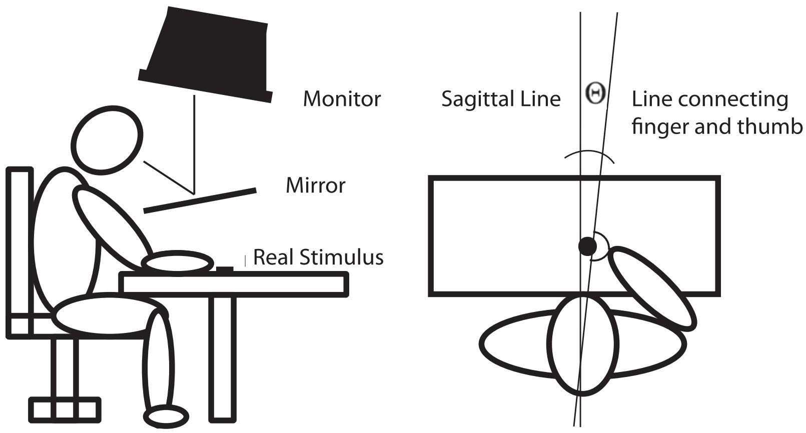

Fig. 1. Left panel demonstrates the mirror setup and how participants were positioned. Participants see virtual object reflected by the mirror, but act on the real objects placed on the table underneath the mirror. Right panel shows participant grasping a disc. The hand orientation θ is defined as the angle between the sagittal direction and the orthogonal projection of the line connecting finger and thumb. θ is positive for counter-clockwise rotation.

experiment and received 8 Euro per hour. All participants were right-handed by self report, had normal or corrected-to-normal visual acuity and were naive with respect to the purpose of the study. One experimental session lasted about 60 min and was undertaken with the understanding and written consent of each participant.

2.2. Apparatus and stimuli

Participants were seated comfortably on an adjustable chair in front of a table. A chin rest guaranteed a constant head position throughout the experiment. Above the table a monitor was installed facing the table. Between table and monitor a 100% reflecting mirror was mounted (Fig. 1). The mirror reflected the images presented on the monitor (Iiyama MA203DT 22", refresh rate 85 Hz). Participants perceived the virtual image as positioned underneath the mirror on the same level as the table. A rectangle and a disc served as virtual target stimuli. A plastic bar (length = 4.1 cm, width = 0.5 cm, height = 0.5 cm) and disc (diameter = 4.1 cm, height = 0.5 cm) served as corresponding real stimuli, respectively. These were placed on the table at precisely the same location that the virtual stimuli were perceived. Consequently, participants reached and grasped for the virtual object below the mirror but felt a real object at the expected location. Lightweight, small metal plates with three infrared light-emitting diodes (IREDs) were mounted to the nails of thumb and index finger of the right hand. Signals were recorded by an Optotrak 3020 system (Northern Digital Incorporation, Waterloo, Ontario, Canada) at a sampling rate of 200 Hz. We were interested in the typical grasp points for index finger and thumb. To this end, a calibration procedure was conducted for each participant prior to the experiment. As a result, we obtained coordinates of typical grasp points defined by the three markers attached to finger and thumb.

2.3. Procedure

At the beginning of each trial, participants were asked to place the index finger and thumb of their right hand on a button which served as starting position. As soon as both fingers were located on the starting position the experimenter placed the target object on the goal position (24 cm away from the starting position) and initiated the trial. Each trial started with a preview of one of the two virtual stimuli, either the disc or the bar. Subsequently, an imperative sound signalled participants to reach for and grasp the virtual stimulus. As soon as they reached the goal sphere (sphere around goal position, with diameter $r = 4.5$ cm), a white noise mask was projected on the mirror. Participants were asked to grasp the real stimuli along their length, lift it with both index finger and thumb and place it halfway between the start and goal position. They were free to choose their movement speed. However, trials in which movement times (time between signal onset and displacement of the physical stimulus 40 mm away from the goal position) exceeded 3 s were marked as errors and repeated later. In 80% of the trials, participants grasped the object which was presented during the preview period, either a bar (bar, no perturbation: BNP) or a disc (disc, no perturbation: DNP). In the remaining 20% of the trials (perturbed trials), the virtual object altered its shape during the movement. With short onset latencies (bar-to-disc, early perturbation: BDEP and disc-to-bar, early perturbation: DBEP, respectively) or late onset latencies (bar-to-disc, late perturbation: BDLP and disc-to-bar, late perturbation: DBLP, respectively), with respect to the movement onset. Early alteration was introduced when finger or thumb were 2 cm away from the starting position. Late alteration was introduced when finger or thumb were 16 cm away from the starting position. Each perturbed trial was presented six times. In addition, each object was presented 48 times without perturbation. Participants started off with five practice trials resulting in a total of 125 trials altogether. The presentation sequence of perturbed and non-perturbed trials was ordered randomly.

3. Data analysis

Finger trajectories were filtered off-line using a second-order Butterworth Filter employing a low-pass cut-off frequency of 15 Hz. For each trial the following parameters were determined. Movement onset was defined as the first frame in which either thumb or index finger exceeded a velocity criterium of 0.1 m/s. Reaction time was defined as duration between go signal and movement onset. Trials in which reaction time was less than 100 ms or greater than 800 ms were excluded. MGA was defined as the aperture size during the reach phase of a grasp (precision grip), where index finger and thumb open maximally. Time at which MGA was reached was defined as TMGA. Touch of object time was defined as the first frame after which finger and thumb had reached a minimum velocity within the target sphere (sphere around goal position, with radius $r = 7$ cm). Movement time (MT) was defined as duration between movement onset and touch of object. To establish baseline differences between grasping a bar and grasping a disc, we compared MGA and the final hand orientation