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Semantic grasping escapes Weber's law

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ABSTRACT

According to Weber's law, the just noticeable difference between stimuli increases proportionally with stimulus magnitude, suggesting that perception becomes more variable when a stimulus becomes larger. Surprisingly, this basic psychophysical principle appears to be violated in grasping because the variability of grasping movements does not increase with object size. This dissociation between perception and grasping has been interpreted either as evidence for different neuronal processing of real-time visual size information [Ganel, T., Chajut, E., Algom, D. (2008a). Current Biology, 18(14), R599–R601], or for the idea that grasping ignores stimulus size and is based on position information only [Smeets, J. B. J., and Brenner, E. (2008). Current Biology, 18(23), R1089–R1090]. Both accounts assume that it is the processing of visual information that leads to the absence of Weber's law in grasping. We show that even if neither visual nor any real-time sensory information about the stimulus is presented (but only abstract, semantic information about its size), grasping does not follow Weber's law. This indicates that other mechanisms must be responsible for the unexpected behavior of grasping.

1. Introduction

According to Weber's law (Baird and Noma, 1978; Fechner, 1860), the just noticeable difference between stimuli increases proportionally with stimulus magnitude. In other words, the uncertainty of the stimulus estimate increases with the magnitude of the stimuli. Weber's law is a basic psychophysical principle, which can be found in almost all sensory dimensions and is supported by a vast amount of data (Baird and Noma, 1978).

Therefore, the finding of Ganel et al. (2008a) that visually guided grasping does not follow Weber's law is particularly astonishing. In their experiments participants performed three different tasks. In the first task, participants estimated the visual size of six randomly presented objects of different sizes (20, 30, 40, 50, 60, and 70 mm) by adjusting the length of a comparison line on a monitor (perceptual adjustment). As predicted by Weber's law, the uncertainty of the size estimates (i.e., standard deviation of the estimates) increased with the object's size. In the second task, participants estimated the size of these objects by adjusting the span between index finger and thumb (manual estimation, assumed to be comparable with perceptual adjustment, but with the advantage of using the same effector as grasping; Goodale, 2011; but see also Franz, 2003). Again, in this task the within-participants standard deviation of the estimates increased with increasing object size, thus, following Weber's law. In the third task, participants grasped these objects. As a measure of uncertainty in grasping, the within-participants standard deviation of the maximum grip apertures (i.e., the maximum opening between index finger and thumb during the grasping movements taken to be a measure of motor-estimated size) was calculated. Astonishingly, this measure did not scale with the object's size. Thus, visually guided grasping does not follow Weber's law. While this result seems like a violation of a very fundamental principle in psychological science, it has been replicated in many studies (Ganel et al., 2008b; Hadad et al., 2012; Heath et al., 2012, 2011; Holmes and Heath, 2013; Holmes et al., 2013, 2011).

Current explanations of the violation of Weber's law in grasping and, hence, the dissociation between grasping and manual estimation regarding Weber's law focus on differences in the processing of the sensory information about the object. At present, there are two influential accounts, the relative–absolute coding account (Davarpanah Jazi and Heath, 2014; Ganel et al., 2008a) and the size–position account (Smeets and Brenner, 2008).

The relative–absolute coding account is based on the perception–action model (Goodale and Milner, 1992; Goodale, 2008, 2011; Milner and Goodale, 1995, 2008). According to the perception–action model, visual information is processed in two largely independent visual pathways. Visual information used for perception is processed in the ventral visual pathway and visual

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information used for action in the dorsal visual pathway. The perception-action model has received support from a comprehensive data base from behavioral, neuropsychological and neuroimaging studies with patients and healthy participants (for review see Goodale, 2011). A fundamental assumption of the perception–action model is that perception and action rely on different neuronal computations of the visual signal (Ganel and Goodale, 2003). Accordingly, the coding of visual size information used for perception (e.g., manual estimation) is based on relative metrics. That is, the neuronal computation of visual size in perception is dependent on the size of surrounding objects or other aspects of the visual scene and on the dimensions of the object itself (i.e., scene-based or allocentric frame of reference). In contrast, the coding of visual size information used for action (e.g., grasping) rests on absolute metrics computed in a body-centered coordinate system (i.e., egocentric frame of reference). That is, the neuronal computation of visual size in action is independent of aspects of the visual scene and the irrelevant dimensions of the object.

This fundamental difference in the neuronal processing of the visual signal has received support from patient studies (e.g., Goodale et al., 1991), studies with healthy participants using pictorial illusions (e.g., Aglioti et al., 1995; Haffenden and Goodale, 1998), and Garner's speeded classification task (Ganel and Goodale, 2003, 2014). However, findings of other authors challenge the conclusions of these studies and provide alternative explanations of the apparent dissociation between perception and action in patient studies (Schenk, 2006, 2012) as well as in studies with healthy participants using pictorial illusions (Franz et al., 2000; for reviews see Bruno and Franz, 2009; Franz and Gegenfurtner, 2008; Schenk and McIntosh, 2010) and Garner's speeded classification task (Eloka et al., in press; Hesse and Schenk, 2013; Janczyk et al., 2010; see also Janczyk and Kunde, 2012).

More direct psychophysical evidence for a fundamental difference in the processing of perception and action is thought to be given by the finding that perceptual tasks, such as perceptual adjustment or manual estimation, adhere to Weber's law, while grasping does not (Ganel et al., 2008a, 2008b; Goodale, 2011). Within the framework of this theory, it is concluded that grasping violates Weber's law because it utilizes absolute visual size information. Manual estimation, in contrast, is assumed to follow Weber's law because it relies on relative visual size information.

According to the perception–action model, only grasping guided by real-time visual information in the movement programming is based on absolute metrics. Memory-based grasping (i.e., after a certain time delay without vision, thus, without visual information at the time of movement programming) rests on relative metrics (Goodale, 2011; Hu and Goodale, 2000). As a consequence, memory-based grasping should follow Weber's law, which was demonstrated empirically (Ganel et al., 2008a, 2008b). However, this finding could not be replicated by other authors (Holmes et al., 2011).

The relative–absolute coding account is not exclusively used to describe differences in the processing within the visual modality. Recently, Davarpanah Jazi and Heath (2014) found a dissociation regarding Weber's law between tactually guided manual estimation and grasping. They placed objects on the participant's left palm (i.e., real-time tactile size information) and asked them to manually estimate the size of these objects or grasp these objects with index finger and thumb of their right hand. Whereas tactually guided manual estimation followed Weber's law, tactually guided grasping did not. In line with the sensory processing model of Dijkerman and de Haan (2007), they conclude that relative size information is used in tactually guided manual estimation and absolute size information is used in tactually guided grasping.

A second approach to explain the dissociation regarding Weber's law was made by the size–position account of Smeets and Brenner (2008). According to their "double-pointing"-hypothesis, grasping can be described as guiding the finger and thumb independently to the grasp points on the object. Consequently, grasping is based on egocentric position information about the grasp points of the object. Thus, in grasping, the computation and the use of the visual size is not necessary. As Weber's law holds for size information, but not for position information, grasping does not follow Weber's law. Manual estimation, in contrast, is based on size information. As a consequence, manual estimation follows Weber's law. Thus, the dissociation regarding Weber's law between manual estimation and grasping is attributed to the use of size information in manual estimation and egocentric position information in grasping. Further, according to Smeets and Brenner (2008), memory-based grasping is based on size information. This is because the memory for size information is assumed to be more accurate than the memory for egocentric position information. While information about object size is not influenced by our own movements, egocentric position information should be updated when we move, which is not possible in memory-based grasping. Accordingly, grasping without real-time visual information about the object is based on relative size information instead of egocentric position information and should follow Weber's law.

In summary, current explanations of the dissociation regarding Weber's law focus on differences in the processing of the sensory information used in manual estimation and grasping. Whereas relative size information is used in manual estimation, either absolute size or egocentric position information is thought to be used in real-time grasping. Memory-based grasping, however, is also thought to be based on relative size information.

However, according to the relative–absolute coding account as well as the size–position account, the violation of Weber's law in grasping is dependent on the availability of real-time sensory information about the object (i.e., concrete sensory information about the object at the time of movement programming; typically visual but also tactile information as in the case of Davarpanah Jazi and Heath, 2014). If no real-time sensory information would be available at the time of movement programming, grasping would be based on relative size information. Thus, both accounts agree that without real-time sensory information grasping should follow Weber's law and the dissociation between manual estimation and grasping should disappear.

To test these accounts, we measured manual estimation and grasping in a visual and a non-visual, semantic condition. In the visual condition, the movement programming of manual estimation and grasping was based on real-time visual information about the objects. In the semantic condition, numbers were presented over headphones indicating the size of objects without vision of these objects. Thus, in the semantic condition neither visual nor real-time (only abstract, memory-based) information about the object was available. According to both accounts, a dissociation between manual estimation and grasping regarding Weber's law is expected in the visual condition but not in the semantic condition.

We also used our experiments to test alternative ideas for the apparent absence of Weber's law in grasping. We hypothesized that there might be other task differences between manual estimation and grasping that could explain the dissociation regarding Weber's law.

First, late noise could mask Weber's law in grasping. This could be noise that occurs in the processing after size is estimated and that does not follow Weber's law (e.g., motor noise). Such late noise will reduce the scaling of the standard deviation, thereby leading to an underestimation of Weber's fraction. If there were more late noise in grasping than in manual estimation, this could account for a smaller Weber's fraction in grasping than in manual estimation. We tested this notion and found that late noise alone