WEBER'S LAW DURING GRASPING

Tzvi Ganel and Erez Freud

Department of Psychology, Ben-Gurion University of the Negev, Beer-Sheva Israel.

Abstract

Visual control of action constitutes a fundamental ability of people when interacting with their visual environment. Visual perception, however, is necessary for recognizing and memorizing different aspects of this environment. Neuroanatomical and neuropsychological evidence supports the notion that different systems mediate visual control of action and visual perception. Here, we will describe a behavioral paradigm to study possible differences in visual sensitivity for object size between visuomotor control and perception. This paradigm is based on applying the measure of Just Noticeable Difference (JND) to the action domain. In a series of experiments, participants were asked to either grasp or make perceptual estimations of objects varying in size. The basic finding throughout all experiments was that Weber's law, a fundamental law governing perception, was violated for visually-guided action throughout the entire movement trajectory. Combining this paradigm with other paradigms used in the literature allows new insights of potential dissociations between the processes underlying perception and action.

A twenty dollar price increase won't probably make a huge change when deciding to buy a new car. The same difference, however, would probably impact our decisions when buying at the grocery store. In the same manner, human's ability to detect changes in small objects' length would be superior compared to their ability to detect the same physical changes for a bigger object. Over a century ago, Weber formulated a basic psychophysical equation which accounts for these perceptual phenomena.

According to Weber, people's sensitivity to changes within a given physical dimension is defined on relative, rather than absolute terms (Baird & Noma, 1978). In other words, the Just Noticeable Difference (JND) of a given stimulus will increase linearly with its physical quantity. Recently, we carried out a series of psychophysical and visuomotor experiments in which participants were asked to either grasp or make perceptual estimations of the length of rectangular objects. JND was defined in this study by using the standard deviation of the mean of the responses for a given stimuli. The logic was based on the classical Method of adjustment according to which, the amount of variance of the responses for a given stimuli reflects an "area of uncertainty" for which subjects are not able to tell the difference between the size comparison and the target object. Indeed, the results of the perceptual experiment were in agreement with Weber's law showing a linear increase in JND's with object's length. Yet, a dissociation was found between perceptual estimations and kinematic measures in this task; unlike the perceptual condition, in which JND's increased with physical size, JND's for grasping were constant and unaffected by the objects' length (Ganel, et al., 2008a; Ganel et al., 2008b). Therefore, Weber's law was violated for visually-guided action but not for perceptual estimation (Figure 1).

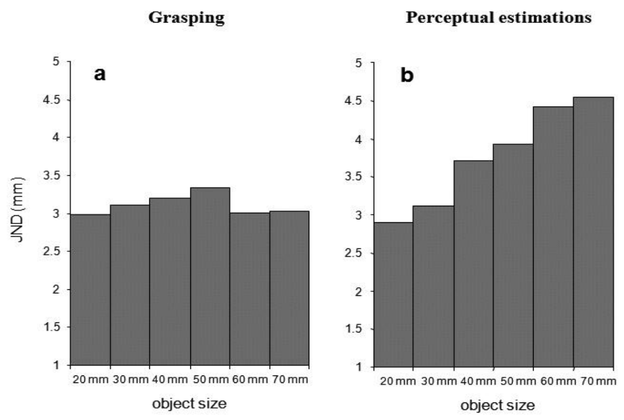

Figure 1: Effects of object size on visual resolution (Just Noticeable Difference – JND) in the behavioral experiments reported by Ganel et al (2008a). a) The effect of object size on JND's during grasping. b) The effect of object size on JND's during perceptual estimations. Note that JND for the perceptual condition increased linearly with length which follows Weber's law. Importantly however, JND was unaffected by size during grasping.

These behavioral results are in accord with Goodale and Milner's influential account of the organization of the primate visual system (Milner & Goodale, 2006). According to their two-visual systems proposal, the ventral 'perception' pathway provides the rich and detailed representation of the world as we see it, and the dorsal 'action' pathway enables flexible control of actions directed to objects in the outside environment. This proposal of a functional separation between visual systems underling action and perception has been supported by converging evidence from different domains. Aside from the behavioral experiments with Weber's law described above, other psychophysical studies have shown that visual illusions, that by definition distort size perception, have little or no effect on visually-guided actions. (Aglioti et al., 1995; Ganel et al., 2008c; but see Frantz et al., 2001).

Since our original publication, several lines of criticisms have been raised regarding our interpretation of our findings and their generality. At the more theoretical level, Smeets and Brenner (2008) have suggested an alternative account according to which grasping movements do not involve computing object's size but are rather based entirely on the locations of the points of intercept for which the fingers grasp the object (Smeets & Brenner, 2001). If indeed the location rather than the size mediates the online control of grasping, Smeets and Brenner have argued that Weber's law is not expected to affect grasping, due to that location is an absolute rather than continuous property of the visual scene. Due to that the present empirical evidence related to the location vs. size debate is scarce, this debate is presently focused at which alternative account provides a more parsimonious explanation for the wealth of empirical data on differences between action and perception. In reply to Smeets and Brenner's (2008) arguments, we have shown that unlike visually-guided grasping, memory-guided grasping, which is known to be mediated by perceptual processing (Goodale et al., 2004) is governed by Weber's law. Smeets and Brenner's theory does not differentiate between visually-guided and memory-guided grasping and therefore does not provide an affective account for this data.

An additional reference on the generality of our findings on Weber's law during grasping was made by two recent papers (Heath et al., 2011, Holmes et al, in press). These authors have argued that Weber's law affects early but not late stages of grasping movements. In our original paper (Ganel et al., 2008a) JND was measured when the distance between the grasping fingers reached a maximum amount (MGA: Maximum Grip Aperture). MGA is used as a basic measure in visually-guided grasping experiments, is achieved during grasping at about 60-70 percent of movement time, and is known to be strongly correlated with object size. When Heath and his colleagues (2011) looked at JND's during the entire movement trajectory, they have argued to find an adherence to Weber's law in early stages of the movement (20-40%). However, these authors have not considered the possible confound velocity during grasping (but see Holmes et al., in press). As Holmes et al. correctly noted, there is a tied relationship between the velocity of the fingers during grasp and the size of the target object. Indeed, in order to minimize the time needed to grasp larger objects, subjects usually open their fingers more abruptly for larger compared to smaller objects (Jakobson & Goodale, 1991). There is also an established relationship in the action control literature between movement variability (the same measure used here to represent JND's) and movement velocity (Meyer et al., 1998). It is not surprising therefore, that the correlation between velocity and object size peeks at the same periods of the movement in which Heath et al. have noticed that JND's showed an increase with size (see Figure 2A). This increase in variability, however, has nothing to do with object size (and therefore, has no relevance to Weber's law) but rather to movement velocity. It is also not surprising that when we statistically removed the relative contribution of fingers velocity from the grasping trajectory, the apparent adherence of JND's during early movement stages to Weber's law have disappeared (Ganel & Freud, in preparation; see Figure 2B). Based on these findings we conclude that Weber's law does not affect grasping during the entire trajectory of the grasping movement.

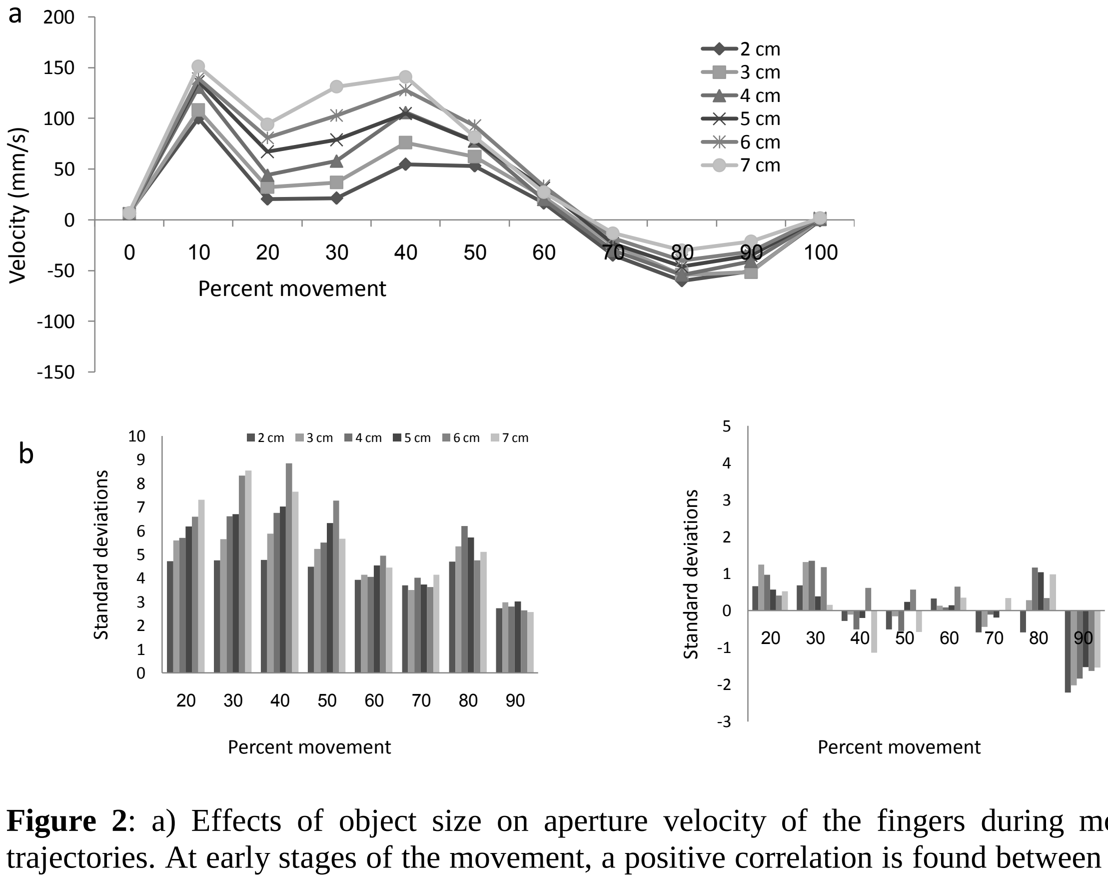

Figure 2: a) Effects of object size on aperture velocity of the fingers during movement trajectories. At early stages of the movement, a positive correlation is found between velocity and object size. b) JND's (as indicated by standard deviations) were also correlated with object size during the same stages of the movement, which was interpreted by others (Heath et al., 2011, Holmes et al, 2011) as an indication that Weber's law affects grasping during early movement. c) When we statistically removed (using a linear regression) the relative contribution of velocity from the movement data, the apparent adherence to Weber's law have disappeared throughout the entire movement trajectory (Ganel & Freud, in preparation).

Conclusions

Weber's law constitutes one of the fundamental attributes of our perceptual arena. Numerous studies have confirmed its important role across different aspects of human perception and cognition. However, most of these studies have neglected the domain of the human action control. Our results show that Weber's fundamental law of psychophysics does not apply for visually-guide action. In light of recent papers arguing against the generality of our findings we provide new evidence that Weber's law does not affect grasping throughout the entire movement trajectory. These findings also call for a new, action-oriented research into the basic aspects of action control and their adherence to basic psychophysical principles.

Acknowledgements

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