Grasping Weber's law

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Ganel *et al.* [1] recently reported what seem to be fundamentally different effects of varying object size on the precision of different tasks. Whereas the standard deviation in the matched size was larger for larger objects, as predicted by Weber's law, the standard deviation in the maximum grip opening was independent of object size. The authors concluded that visual coding for grasping does not obey Weber's law. We argue that the difference in performance they observed can readily be understood if one considers the sources of information that contribute to each task. Judgments of size should follow Weber's law, but judgments of position should not. Following our earlier suggestion that grasping is based on position information [2], we therefore would not expect grasping to follow Weber's law. We can account for the performance in all three tasks using reasonable values for perceptual precision. We argue therefore that there is no fundamental violation of Weber's law, just an incorrect assumption about the information that is used for grasping.

Weber's law is the name given to the widely observed phenomenon in perception that the just-noticeable difference in a physical property is a fixed proportion of its magnitude. It is important to realize that Weber's law can hold only for physical properties that have a magnitude — those that start at an absolute zero and cannot be negative. Weber's law holds for perception of size, weight and distance; it does not hold for orientation or position. The fact that position and orientation are not described using magnitudes — there is no absolute zero for positional coordinates and orientations, and their values can be negative — is reflected in the fact that the precision of position and orientation are more or less independent of their value. Considering this distinction we can conceive of an apparent inconsistency: we predict that the perceived size of a line will obey Weber's law, but that the perceived locations of its endpoints will not. The judgments underlying this inconsistency coexist in our brain without being noticed, but they are revealed when a task that mainly relies on the locations of a line's endpoints is compared with one that mainly relies on the length of the same line [3,4]. This distinction between position and size is essential for understanding Ganel *et al.*'s [1] results, because the violation of Weber's law is completely logical if one considers that the control of grasping is based on positions rather than size [2,5,6]. As the perception of position does not follow Weber's law, grasping should not follow Weber's law, which is what Ganel *et al.* [1] reported. This is nice support for grasping relying on positions rather than size, and needs no further explanation. To demonstrate this we will interpret their data quantitatively.

In order to understand the data one must realize that the measured variability consists of two components: the variability in judging the visual measure of interest and the variability in indicating the response. For grasping, the visual measures of interest are the *positions* of the grasping points on the object. For the other two tasks, the measure of interest is the object *size*. When grasping an object or indicating its size by matching it with a grip aperture (manual matching) the variability in indicating the response is determined by the spatial resolution of afferent and efferent information about the location of the digits. For visual matching the variability in indicating the response is determined by a combination of monitor resolution and mouse precision. In all cases the variability will also depend on how quickly subjects try to perform the task. The total variance (squared standard deviation) will be the sum of the perceptual variance and the variance in responding.

Having identified the sources of variability, we can describe the data of the three tasks used by Ganel *et al*. [1] with four parameters (Figure 1). The data from the visual matching task are described by combining a Weber fraction k_{vs} = 0.06 for visual size judgement with a response precision σ_{vr} = 1.2 mm for visual matching. The data from the manual matching task are described by combining the same Weber fraction k_{vs} = 0.06 with a precision σ_{fr} = 2.5 mm for responding by positioning the fingers. The grasping data are described by the same precision in positioning the fingers, but instead of combining it with the

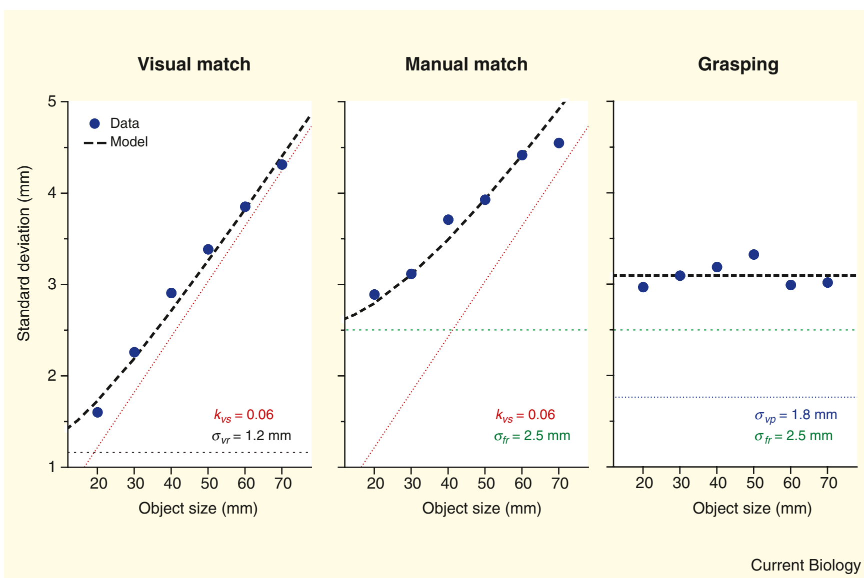

Figure 1. The data from the three tasks of Ganel *et al.* [1] and our interpretation.
The thick dashed curve shows the fit of our simplistic four-parameter model. The thin lines show the contributions of the two relevant sources of variability for each task (thin dotted lines: visual judgement; thin dashed lines: response imprecision).

Weber fraction for size, we combine it with a visual precision for position σ_{vp} = 1.8 mm. The curves in Figure 1 show the outcome of this simple model.

The fact that we can describe the experimental curves for three different tasks with only four parameters is a first step towards quantitative support of our interpretation of the data. The second step is to check whether the values of the parameters are reasonable. The simplest parameter to compare with the literature is the Weber fraction for size perception, which other authors have also reported to be 0.06 [7,8]. The visual precision for position of 1.8 mm corresponds to 0.34° (at the distance of 30 cm used in the experiment), which is within the 0.2°–0.6° range reported in the literature [9]. The precision in positioning the fingers is presumably determined by the resolution of proprioception. Our estimate of 2.5 mm is about 30% worse than the estimated 1.8 mm for visual precision, which again is in line with the values reported in the literature [9].

The data provided by Ganel *et al.* [1] show that, for objects that are larger than about 3 cm, relying on the positions of the object's edges is more precise than relying on the object's size. This is probably one of the reasons for relying on positions, rather than relying on size, in visually guided grasping. If the object that is to be grasped is removed from sight before it is grasped, then relying on (remembered) positions becomes less advantageous because the memory of size is much more precise than that of position. The reason for this is that our own movements do not influence information about the object's size (a magnitude), whereas information about the egocentric position has to be updated whenever we move. Thus, for a remembered target, the subjects will not use the position-based grasping strategy, but will use size information instead [10]. This means that Weber's law should hold for delayed grasping, which is what Ganel *et al*. [1] show to be the case in their Figure 2.

We conclude that all three tasks conform to the classical psychophysical laws and even to the known precision of the relevant perceptual variables. There is therefore no need to postulate any fundamental differences in processing between the tasks. The experimental evidence reported by Ganel *et al.* [1] gives further support for our view that visually guided grasping can be regarded as controlling the individual digits on the basis of position information [2,6], as opposed to the more classical view that grip aperture is controlled on the basis of perceived size [11,12], or Milner and Goodale's [13] view that grip aperture is controlled on the basis of a separate representation of size. Thus, visual coding for action obeys all fundamental psychophysical principles.

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Response: When does grasping escape Weber's law?

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In a recent study [1], we found that Weber's law, a fundamental principle of perception, does not govern visual control of grasping and concluded that different representations of object size are used for action and for perception [1]. Smeets and Brenner [2] suggest instead that grasping is computed on the basis of position rather than on the basis of size, and that this accounts for the apparent absence of Weber's law. However, their alternative explanation cannot readily account for memory-based grasping, which does obey Weber's law. In this response, we present additional data to show that, even when memory-based and real-time grasping both are executed without visual feedback, only the former obeys Weber's law. This dissociation further supports the conclusion that action and perception are sustained by qualitatively different computations.

Object size is processed differently for visually-guided action and for perception. Visual illusions that readily distort size perception [3,4] have little, if any, effects on grasping. For a single object, people are often unable to perceive the size of one dimension independently of the other dimensions, yet grip scaling is unaffected by the same dimensions [5]. In that study, we calculated Garner interference — a measure of the failure of selective attention — for perception and action with respect to a given attribute of the same object. Garner interference was found for perception but not for action, exhibiting a dissociation between the two visual systems at the basic level of attention. Recently, we have shown that, for grasping, the resolution power of size is independent of object size [1]. This violation of Weber's classic psychophysical law provides compelling evidence that vision-for-action and vision-for-perception do not

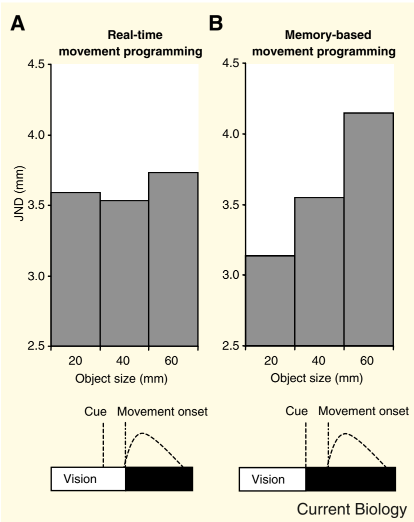

Figure 1. Effects of object length on visual resolution.

(A) In the real-time condition, grasping could be programmed based on real-time visual information. (B) In the memory-based condition, vision was occluded prior to the programming of the grasp, requiring it to be based on memory representations. The just noticeable difference (JND) was unaffected by object size in the real-time condition ($F(1,43) < 1$, $p > 0.1$). This violation of Weber's law replicates our previous findings, but now under an open-loop condition in which visual feedback was not allowed. Importantly, in the memory-based condition, in which vision was occluded during movement programming, the JND increased with object size in a linear fashion ($F(1,43) = 12.36$, $p < 0.01$) in accordance with Weber's law. A significant interaction was found between the linear components for the real-time and memory-based conditions ($F(1,43) = 4.9$, $p < 0.05$). Bottom panels show an overview of the experimental design. (See Supplemental data for details.)

follow the same psychophysical principles [6,7].

Smeets and Brenner [2] argue that the reason grasping violates Weber's law is that position, not size, is the relevant variable for manual prehension. Their argument is derived from their earlier proposal that each of the digits of the grasping hand is independently directed to a different location in space [8]. In their view, the apparent relationship between grip aperture and the size of the goal objects is simply an epiphenomenon. As a consequence, they argue, the resolution of the grasping hand should remain unaffected by changes in absolute size and grip scaling should be insensitive to common visual illusions. It would appear therefore that Smeets and Brenner's [2] size-position account and our perception-action account can both comfortably explain these sets of observations — but for quite different reasons.

There is one line of evidence, however, that follows directly from the perception-action account that creates some difficulty for Smeets and Brenner's [2] argument. According to the perception-action model, the programming of a grasping movement towards an object that is no longer visible must rely on a memory of the object that was originally laid down by perception. As a consequence, memory-driven grasping should be affected by the same variables known to affect perception, an idea that is supported by a wealth of neuropsychological, neuroimaging, and behavioural data [6,7]. One would predict therefore that memory-driven grasping should obey Weber's law. And, this is exactly what we found in our study [1]: When grasping was delayed and made in the dark (that is, in 'open loop'), the resolution of grip aperture decreased with object size in accordance with Weber's law. Smeets and Brenner's [2] model, in contrast, makes no predictions at all about what should happen with memory-based grasping.

In our earlier study, visual feedback was available for real-time grasping but not for memory-based grasping. To rule out a role of feedback, we report the results of an experiment in which vision was occluded during grasping in both conditions. In real-time grasping, vision was occluded following movement initiation, hence still allowing the programming of movement based on real-time visual information [9]. In memory-based grasping, vision was occluded following an auditory 'go' cue, hence the programming of the grasp could be based on memory only.

As can be seen in Figure 1, resolution was invariant in the real-time condition. In the memory-based condition, by contrast, resolution decreased with object size in accordance with Weber's law. This contrast, replicating our original findings, follows directly from the perception-action model. The size-position account cannot explain these results without making additional assumptions (for example, positing that real-time grasping uses position cues whereas memory-guided grasping uses size).

Finally, talking about position as a magnitude-free variable, Smeets and Brenner [2] are in danger of abandoning the basic notion of psychophysical function as well as the laws of Fechner, Stevens and Ekman [10]. This is a very high price to pay. Our perception-action model thus has the virtue of being favored by Occam's razor — accounting for a huge range of data from single-unit recording in the monkey to human psychophysics.

Supplemental Data

Supplemental data are available at http://www.current-biology.com/supplemental/S0960-9822(08)01333-X.

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