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Visually and memory-guided grasping: Aperture shaping exhibits a time-dependent scaling to Weber's law

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ABSTRACT

The 'just noticeable difference' (JND) represents the minimum amount by which a stimulus must change to produce a noticeable variation in one's perceptual experience and is related to initial stimulus magnitude (i.e., Weber's law). The goal of the present study was to determine whether aperture shaping for visually derived and memory-guided grasping elicit a temporally dependent or temporally independent adherence to Weber's law. Participants were instructed to grasp differently sized objects (20, 30, 40, 50 and 60 mm) in conditions wherein vision of the grasping environment was available throughout the response (i.e., closed-loop), when occluded at movement onset (i.e., open-loop), and when occluded for a brief (i.e., 0 ms) or longer (i.e., 2000 ms) delay in advance of movement onset. Within-participant standard deviations of grip aperture (i.e., the JNDs) computed at decile increments of normalized grasping time were used to determine participant's sensitivity to detecting changes in object size. Results showed that JNDs increased linearly with increasing object size from 10% to 40% of grasping time; that is, the trial-to-trial stability (i.e., visuomotor certainty) of grip aperture (i.e., the comparator) decreased with increasing object size (i.e., the initial stimulus). However, a null JND/object size scaling was observed during the middle and late stages of the response (i.e., >50% of grasping time). Most notably, the temporal relationship between JNDs and object size scaling was similar across the different visual conditions used here. Thus, our results provide evidence that aperture shaping elicits a time-dependent early, but not late, adherence to the psychophysical principles of Weber's law.

1. Introduction

The 'just noticeable difference' (JND) represents the minimal alteration in stimulus intensity that produces a noticeable variation in one's perceptual experience and is related to initial stimulus magnitude. In particular, Weber's law states that JND magnitude is a constant proportion to the original stimulus value and that the sensitivity of changes in any physical continuum is relative as opposed to absolute.[1] Although the importance of Weber's law is recognized by its generalizability to perception-based processing in multiple sensory domains (e.g., proprioceptive, visual, auditory) a paucity of work has examined extension of the law to the motor domain.

In recognition of the above, Ganel, Chajut, and Algom (2008) computed JND magnitudes to examine whether goal-directed grasping conforms to Weber's law. In their study, participants grasped objects of different widths (i.e., 20, 30, 40, 50, 60 and 70 mm or 20, 40 and 60 mm) when vision was available throughout the response (closed-loop grasping), when occluded at movement onset (open-loop grasping), and when occluded 5000 ms in advance of response cuing (memory-guided grasping) (see also Ganel, Chajut, Tanzer, & Algom, 2008).[2] Notably, within-participant standard deviations of peak grip aperture size were used to determine participant's sensitivity to detecting changes in object size (i.e., the JND scores). Ganel et al. reported that JNDs for closed- and open-loop grasping did not vary in relation to object size. In contrast, corresponding values for memory-guided grasping increased linearly with increasing object size; that is, the trial-to-trial stability (i.e., visuomotor certainty) of peak grip aperture (i.e., the comparator) decreased with increasing object size (i.e., the initial stimulus).

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[1] Weber had participants pick-up a standard weight (i.e., the initial stimulus) and then a comparison weight and observed that the greater the weight of the standard, the greater the difference between the standard and the comparison weight had to be before a between-hand difference in load was detected.

[2] The original work of Ganel, Chajut, and Algom (2008) included a closed-loop visual condition and a 5000 ms memory-guided grasping condition. In a published Response article to criticism by Smeets and Brenner (2008), Ganel, Chajut, and Algom (2008) contrasted a 0 ms delay to an open-loop grasping condition. This manipulation was completed so that both grasping tasks were implemented without online visual feedback.

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Moreover, the memory-guided task elicited a JND/object size scaling on par to that observed in a manual estimation task (i.e., a perceptual task). Hence, Ganel et al. proposed that visually derived grasping (i.e., closed- and open-loop) demonstrates a fundamental violation of Weber's law whereas memory-guided grasping shows a fundamental adherence to the law's psychophysical properties.

Ganel, Chajut, and Algom (2008) and Ganel, Chajut, Tanzer, et al. (2008) interpreted their results within the framework of Goodale and Milner's (1992) perception/action model (PAM). Specifically, the PAM asserts that unitary and absolute visual information mediated by the dedicated visuomotor networks of the dorsal visual pathway support actions planned and/or implemented with real time visual feedback (i.e., closed- and open-loop actions). Notably, occluding vision *prior to* movement onset is thought to disrupt the real time operation of dorsal visuomotor networks (Westwood & Goodale, 2003; for review see Goodale & Westwood, 2004). Accordingly, the PAM states that unitary and relative visual information maintained by the temporally durable visuoperceptual networks of the ventral visual pathway support memory-guided actions. Given this framework, Ganel et al. proposed that visually derived grasping violates Weber's law due to their mediation via absolute visual information. In turn, it was concluded that memory-guided grasping adheres to the perceptual properties of Weber's law due to their mediation via relative visual information.

Recent work by Heath, Mulla, Holmes, and Smuskowitz (2011) sought to build upon Ganel, Chajut, and Algom (2008) and Ganel, Chajut, Tanzer, et al.'s (2008) findings and examine whether aperture shaping for visually derived actions elicit a temporally invariant violation of Weber's law. The motivation for this work was twofold. First, Ganel et al's examination of JND/object size scaling was limited to the time of peak grip aperture. Because this variable represents a late occurring metric (i.e., ~70% of grasping time: Jeannerod, 1984) it was unclear whether aperture shaping would exhibit *in toto* violation of Weber's law. Second, although the theoretical tenets of the PAM assert that unitary absolute and unitary relative visual information support the unfolding parameters of visually derived and memory-guided actions, respectively, there is some evidence from the pictorial illusions literature that the perceptual properties of a visual array impact the early, but not late, stages of aperture shaping (Glover & Dixon, 2001, 2002). In fact, Glover's (2004) planning/control model (PCM) states that a planning representation mediated by relative visual information supports the early kinematic parameterization of a response whereas a control representation supported by absolute visual information gradually assumes command of the unfolding response. Given the above, Heath et al. (2011) had participants grasp differently sized objects (i.e., 20, 30, 40, 50 and 60 mm) in closed- and open-loop visual conditions and JND values were computed not only at the time of peak grip aperture, but also at normalized deciles of grasping time (i.e., 10–90% of grasping time). Results for closed- and open-loop trials showed a linear increase in JNDs as a function of increasing object size during the early stages of aperture formation (i.e., 10–50% of grasping time). However, from 60% to 90% of grasping time (and including the time of peak grip aperture), a null relationship was observed between JNDs and object size. Such findings demonstrate a temporally dependent early adherence and late violation of Weber's law and provide some support for the PCM's assertion that relative and absolute visual information contribute to the respective early and late specification of grip aperture.

The goal of the present study was to determine if memory-guided grasping exhibits a time-dependent adherence (or violation) to Weber's law that is distinct from visually derived grasping. Recall Ganel, Chajut, and Algom (2008) and Ganel, Chajut, Tanzer, et al. (2008) report that JNDs for memory-guided grasping increased with increasing object size and their interpretation that such a result supports the PAM's contention that even the briefest period of visual delay (i.e., 0 ms) results in motor output that is supported via unitary and relative visual information. In contrast, the PCM asserts that removal of visual information regarding the effector or the target subjects the control representation to a gradual decay over a period of roughly 2000 ms; that is, "…when the delay is more than two seconds, the decay will be nearly complete, and movements made after delays much longer than two seconds will be executed entirely 'as planned' (i.e., without the benefit of online control)" (Glover, 2004; p. 5). Accordingly, the PCM asserts that the absolute properties of the control representation are available to support the later stages of action given a sufficiently brief delay (i.e., <2000 ms). In line with Heath et al. (2011), we had participants grasp differently sized objects and computed JNDs at the time of peak grip aperture as well as at decile increments of normalized grasping time. Importantly, closed- and open-loop conditions were contrasted with memory-guided conditions involving a brief (i.e., 0 ms) and a longer (i.e., 2000 ms) visual delay. In terms of research predictions, if the PAM is correct then both the 0 and 2000 ms delay conditions should demonstrate JNDs that scale to object size during the early, middle and late stages of the response. In this framework, the unitary and relative visual percept supporting memory-guided grasping should produce a temporally invariant adherence to the perception-based properties of Weber's law. Alternatively, if the PCM is correct, then the 0 and 2000 ms delay conditions are predicted to give rise to an early, but not late, scaling of JND magnitudes to object size. In this framework, the relative visual information supporting the early kinematic parameterization of action is predicted to give rise to JND/object size scaling. In turn, the absolute visual information supporting the middle and late stages of grip aperture shaping is predicted to give rise to a null JND/object size scaling. In other words, the dynamic nature of the visual information supporting memory-guided actions is predicted to produce a temporally dependent early adherence and late violation of Weber's law.

2. Methods

2.1. Participants

Fourteen (nine male and five female: age range = 19–27 years of age) self-declared right-handed participants with normal or corrected-to-normal vision were recruited from the University of Western Ontario community. Participants provided informed consent and this work was approved by the Office of Research Ethics, University of Western Ontario, and conducted according to the ethical standards of the Declaration of Helsinki.

2.2. Apparatus and stimuli

Participants stood for the duration of the experiment in front of a normal tabletop (height of 880 mm: surface width and depth of 1040 mm and 740 mm, respectively) and manually estimated (i.e., perceptual task) or grasped (i.e., motor task) the long-axis of target objects. Target objects were painted flat black and were 20, 30, 40, 50 and 60 mm in length and 10 mm in depth and height and were presented against a flat white surface (i.e., a neutral visual background). The long-axis of target objects was presented perpendicular to the midline of participants at a distance of 500 mm (depth plane) from the front edge of the tabletop. A small switch (i.e., start location) was affixed to the tabletop midline and placed 50 mm from its front edge. Vision of the grasping environment was manipulated via liquid–crystal occlusion goggles (PLATO Translucent Technologies, Toronto, ON, Canada) and all visual and auditory events were controlled via MatLab (7.6: The Mathworks, Natick, MA, USA) and the Psychophysics Toolbox extensions (ver 3.0; see Brainard, 1997).