Action is immune to the effects of Weber's law throughout the entire grasping trajectory

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Vision for action and vision for perception have been suggested to be mediated by overlapping yet dissociable mechanisms. Recent evidence provided basic psychophysical support for this suggestion. In particular, it has been shown that Weber's law, the decrease in visual resolution with object size, does not affect the maximum grip aperture (MGA) between the fingers prior to grasp. Several studies replicated this result, but have argued that grasping may still obey Weber's law at early movement stages. Here, we show that this apparent adherence to Weber's law was confounded by task demands. Specifically, subjects were asked to keep their fingers closed prior to grasp, which encouraged them to open their fingers faster for larger compared to smaller objects. In two experiments, we tested this proposal by disentangling the effects of velocity from those of Weber's law. In Experiment 1, subjects were asked to keep their fingers open wide-apart prior to grasp, which encouraged them to close their fingers faster, rather than slower, to smaller objects. Now, the apparent adherence to Weber's law was reversed, and higher resolution was found for larger compared to smaller objects, thus indicating a "reversed" Weber's law. In Experiment 2, we manipulated task demands to equate aperture velocities across different objects sizes. When velocity was equated, no effects of Weber's law were found throughout the movement. These findings show that previous studies have confounded visual resolution with fingers' velocity, which led to an erroneous conclusion that Weber's law affected grasping at early stages of the movement.

Introduction

Over a century ago, Weber (1834) formulated one of the fundamental principles governing human perception. According to Weber's law, people's ability to detect changes within a given physical dimension linearly decreases with stimulus size (Baird & Noma, 1978). In light of the wealth of evidence the supports the validity of Weber's law across virtually all domains of human perception (Stevens, 1975), little attention has been devoted to the question of whether or not Weber's law applies to the domain of visuomotor control. This lapse of attention is even more surprising given the widely accepted model according to which vision for action and vision for perception are mediated by dissociable neural and cognitive mechanisms (Goodale & Milner, 1992; Milner & Goodale, 2008; Milner & Goodale, 2006).

In a series of studies, we provided evidence for dissociations between perception and action in their adherence to Weber's law (Ganel, Chajut, & Algom, 2008; Ganel, Chajut, Tanzer, & Algom, 2008; Hadad, Avidan, & Ganel, 2012). In these experiments, participants were asked to either grasp or make perceptual estimations of the length of rectangular objects. Just Noticeable Differences (JNDs) were defined by 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

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the target object. Standard deviations have been used as a measure for JNDs in various perceptual domains such as time perception (e.g., Getty, 1975, 1976; Gibbon, 1977; Kristofferson, 1980), numerical cognition and magnitude processing (e.g., Cordes, Gallistel, Gelman, & Latham, 2007; Gallistel & Gelman, 2000; Nieder & Miller, 2003; Whalen, Gallistel, & Gelman, 1999), weight perception (e.g., Evans & Howarth, 1966), and auditory perception (e.g., Van Tasell & Folkeard, 2013; Wier, Jesteadt, & Green, 1976). In all these examinations, JNDs (measured by standard deviations) generally obeyed Weber's law.

Here, we focus on the domain of size perception and on differences between the way size is computed for grasping and for perceptual estimations. JNDs for grasping were measured at the point of time in which the distance between the grasping fingers reached a maximum amount (MGA: Maximum Grip Aperture), an established measure for sensitivity to object size in visually-guided grasping experiments. MGA is usually achieved at about 60%–70% of movement time, and is known to be closely correlated with object size (Bootsma, Marteniuk, MacKenzie, & Zaal, 1994; Ganel, Freud, Chajut, & Algom, 2012; Gentilucci, Chieffi, Scarpa, & Castiello, 1992; Jakobson & Goodale, 1991; Marteniuk, Leavitt, MacKenzie, & Athenes, 1990). Unlike perceptual estimations, that obeyed Weber's law (showing a linear increase in JND with object size), JNDs for grasping were unaffected by object size (Ganel, Chajut, & Algom, 2008; Ganel, Chajut, Tanzer, et al., 2008; Hadad et al., 2012). Weber's law was therefore violated for visually-guided action but not for perceptual estimations.

Several studies have further looked at the effects of Weber's law on grasping. Unlike in our original paper, in which we focused our analysis on the effect of Weber's law on MGAs, which are achieved in the second half of the movement trajectory, these studies have measured the effects of Weber's law throughout the entire movement trajectory (Heath, Mulla, Holmes, & Smuskowitz, 2011; Holmes & Heath, 2013; Holmes, Lohmus, McKinnon, Mulla, & Heath, 2013; Holmes, Mulla, Binsted, & Heath, 2011). The results have generally replicated our main finding regarding the point in time in which MGA is achieved, but showed that during early stages of the movement (peaking at about 30% of the movement trajectory), and in line with Weber's law, larger *SD*s were found for bigger compared to smaller objects. This effect was limited only for the first third of the movement and was absent later at the point of the time MGA has occurred. The authors have used this evidence to argue that Weber's law can affect grasping, but only during early stages of the movement.

Although the findings that *SD*s were larger for bigger compared to smaller objects at early stages of the movement seem to be appealing, one cannot embrace the conclusion that Weber's law affects grasping before considering a possible confound, that of fingers' velocity. In particular, in most grasping studies, participants are asked to keep their thumb and finger closed together prior to each grasp. In order to efficiently grasp the object, this encourages participants to open their fingers faster for bigger compared to smaller objects (Foster & Franz, 2013; Heath et al., 2011). This pattern of faster aperture velocities for bigger compared to smaller objects is observed only during the first third of the movement, exactly at the same time in which larger *SD*s are found for bigger objects (Heath et al., 2011). This mutual occurrence of faster velocities and larger performance errors (an increase in *SD*s) is probably non-incidental, and could reflect a basic effect of a speed accuracy-tradeoff: Quicker opening of the fingers leads to larger deviations in grip aperture (for a similar idea, reflected in Fitt's law, see Khan, Elliot, Coull, Chua, & Lyons, 2002; Meyer, Abrams, Kornblum, Wright, & Smith, 1988). In other words, although a finding of larger *SD*s for bigger objects seems to support the idea that aperture is affected by object size (and therefore, that grasping is affected by Weber's law), it is also possible that this pattern of results is generated entirely by the velocity of the fingers rather than by objects' size per se.

Two recent studies have addressed the potential effects of velocity on *SD*s in grip aperture at early stages of the grasping. In a theoretical dispatch, Foster and Franz (2013) used simulated modeling data to propose that when velocity is taken into account, there is no indication of the effect of Weber's law during early stages of the grasping movement. Furthermore, these authors have argued that the point of time in which MGA is achieved can be the only valid measure to test the effects of Weber's law on grasping. Only at this point of time, aperture velocity is zero (the fingers' aperture direction alternates from opening to closing on the object prior to grasp), and therefore cannot potentially affect *SD*s. In a recent empirical study, Heath and his colleagues (Heath, Holmes, Mulla, & Binsted, 2012) have also tried to address the issue of the effects of velocity on *SD*s by comparing performance between speeded grasping (completed within 400 ms from grasp initiation) and normal grasping (completed within 800 ms). These authors reported significant effects of object size on *SD*s in both conditions, and argued that these findings do not support the idea that velocity can account for the early effects of Weber's law during grasping. Yet, as in previous studies, subjects in Heath et al.'s (2012) study were asked to keep their fingers closed together prior to each grasp, which again led to faster aperture velocities for larger for compared to smaller objects even in the speeded grasping condition. Therefore, the possible confound of aperture

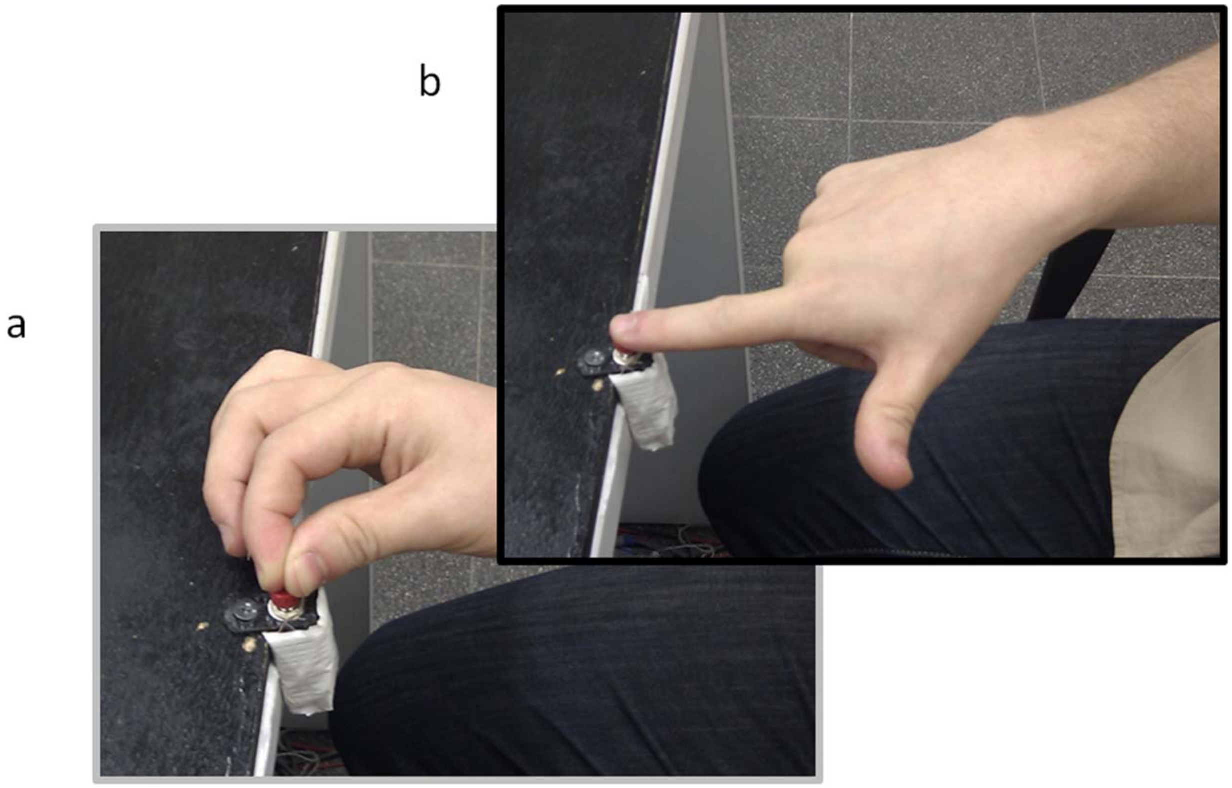

Figure 1. An illustration of the way participants' fingers were preshaped prior to grasps in previous studies (a) and in the current study in Experiment 1 (b). In previous studies, participants were asked to keep their fingers closed together prior to each grasp, which encouraged them to open their fingers faster to bigger compared to smaller objects. In Experiment 1, participants were asked to open their fingers wide-open prior to each grasp, which encouraged them to close their fingers faster for smaller rather than for bigger objects.

velocity could still account for the apparent effect of Weber's law during grasping in this study.

Experiment 1

In the current study, we directly controlled for the effects of velocity on grasping by manipulating the initial distance between the grasping fingers prior to grasp. To unconfound the effects of velocity from those of object size, participants were not asked to keep their fingers closed prior to each grasp. Instead, in Experiment 1, we asked subjects to open their thumb and finger wide apart prior to each grasp (see Figure 1). We hypothesized that under these experimental settings, participants would tend to close their fingers faster to smaller as compared to larger objects (for a similar design in which the subjects were asked to open their fingers wide-open prior to grasp, see Saling, Mescheriakov, Molokanova, Stelmach, & Berger, 1996; Timmann, Stelmach, & Bloedel, 1996). To the extent that the results of previous studies were triggered by object size rather than by velocity, it is expected that even under these conditions, *SD*s would be larger for bigger compared to smaller objects during initial stages of the grasping movement. If, however, velocity rather than object size confounded the results of previous studies, as we hypothesize, it is predicted that *SD*s would be larger for faster velocities leading to a reversal of the relationship previously found between *SD*s and object size. In particular, it is expected that smaller (instead of larger) *SD*s would be found for bigger objects, which would, of course, indicate the opposite to what Weber's law is predicting.

Methods

Participants

Eighteen healthy undergraduate students with normal or corrected-to-normal vision participated in the experiment. The data from two participants were discarded due to a technical failure in data registration. The participants provided informed consent to participate in the experiment and received the equivalent of $5 for their participation. All experimental procedures were approved by the ethics committee of the Psychology Department at Ben-Gurion University of the Negev.

Apparatus and stimuli

Participants sat in front of a black tabletop on which a circular disc was placed at the viewing distance of 40 cm. Computer controlled PLATO goggles (Translucent Technologies, Toronto, ON) with liquid-crystal shutter lenses were used to control stimulus exposure time. Grip scaling was recorded by an Optotrak Certus device (Northern Digital, Waterloo, ON). The apparatus tracked the 3D position of three active infra-red light emitting diodes attached separately to the participant's index finger, thumb, and wrist. This experimental apparatus allowed for complete movement freedom of the hand and fingers. A 200 Hz sampling rate was used for the Optotrak, which provides a 0.1 mm positional accuracy under the specified experimental conditions. The target objects were 10 mm thick circular disks which differed in diameter (30 mm, 40 mm, and 50 mm).

Experimental procedure

The target object was placed 20 cm in front of the participant's initial hand position. The order of the trials and object sizes was pseudo-randomized and counterbalanced across subjects. Prior to each trial, the participants were asked to open their thumb and finger wide apart while their index finger was touching a central start button (Figure 1). Each trial began with the opening of the goggles which was followed by a 500 ms interval and then by an auditory beep which served as a "go" signal to start grasping the target object. Participants were asked to grasp the objects in a natural manner. The goggles remained open for additional 2000 ms to allow complete visual feedback during each grasp. Following a short practice and equipment-calibration, each subject performed 60 consecutive experimental trials (20 repetitions of each object size).

Data analysis

On each trial, we recorded the 3D trajectories of the fingers during grasp. Movement onset was defined as the point where the velocity of the finger aperture was above 5 mm/s for 15 consecutive frames (75 ms). Movement offset was defined as the point where the wrist velocity decreased below 20 mm/s for 15 consecutive frames. Velocity was computed by the resultant distance between the apertures in frames i and i+1 divided by the time difference between the two frames. No filtering was applied on the data.

As in previous studies that looked at movement trajectories during grasp (Ganel et al., 2012; Heath et al., 2011), movement was divided to 11 normalized time points (0% signifies the point of movement initiation and 100% the point in which final grasping was achieved, in gaps of 10%). Movement trajectories were then computed for each of the 11 time points. These computations included the aperture between thumb and index finger, the velocity of the aperture, and the *SD* (standard deviation of the aperture between the fingers).

Design

Normalized movement time (11 levels) and object size (three levels) served as within-subject independent variables. Fingers' aperture, *SD*s, and velocity served as the dependent variables.

Results and discussion

The purpose of Experiment 1 was to test whether previous results showing an increase in *SD*s for bigger compared to smaller objects during early stages of the movements were mediated by fingers' velocity rather than by the adherence to Weber's law.

The aperture between the fingers was measured along the grasping. The maximum gap between the fingers was recorded at the beginning of the movement as required by the experimental demands. As can be seen in Figure 2a, sensitivity to object size appeared at early parts of the movement trajectory. Note that at around 50% of the movement time, participants reached a minimum aperture that was followed by a small reopening of the fingers prior to closing on the object for the final grasp. This pattern of aperture could have reflected an automatic tendency to begin the final stage of the grasping movement from a point in which the aperture between the fingers is smaller than the actual size of the object to be grasped (Hesse & Deubel, 2009; Saling et al., 1996; Timmann et al., 1996).

The analysis of the absolute aperture velocity (Figure 2b) revealed main effects of object size, $F(2, 30) = 27.74$, $p < 0.001$, $\eta_p^2 = 0.65$, and of movement time, $F(10, 150) = 42.5$, $p < 0.001$, $\eta_p^2 = 0.74$. A two way interaction between movement time and object size, $F(20, 300) = 12.75$, $p < 0.001$, $\eta_p^2 = 0.45$, indicated that aperture velocities for different object sizes showed a different pattern at different stages of the movement. More important, as we predicted, aperture velocities during the first part of the movement were faster for smaller objects. Planned comparisons confirmed that this effect was significant at initial stages of the movement (10%–40%), with a reverse linear trend during the first four movement time points, in which faster aperture velocities were found for smaller, compared to larger objects, $F(1, 15) = 6.37$, $p < 0.05$; $F(1, 15) = 25.26$, $p < 0.01$; $F(1, 15) = 39.78$, $p < 0.01$; $F(1, 15) = 13.97$, $p < 0.01$ for the 10%, 20%, 30%, 40% time points, respectively. At 60% of the movement, slower velocities were observed for smaller objects, $F(1, 15) = 5.88$, $p < 0.05$. This result corresponds with the aperture data, for which at 50% of

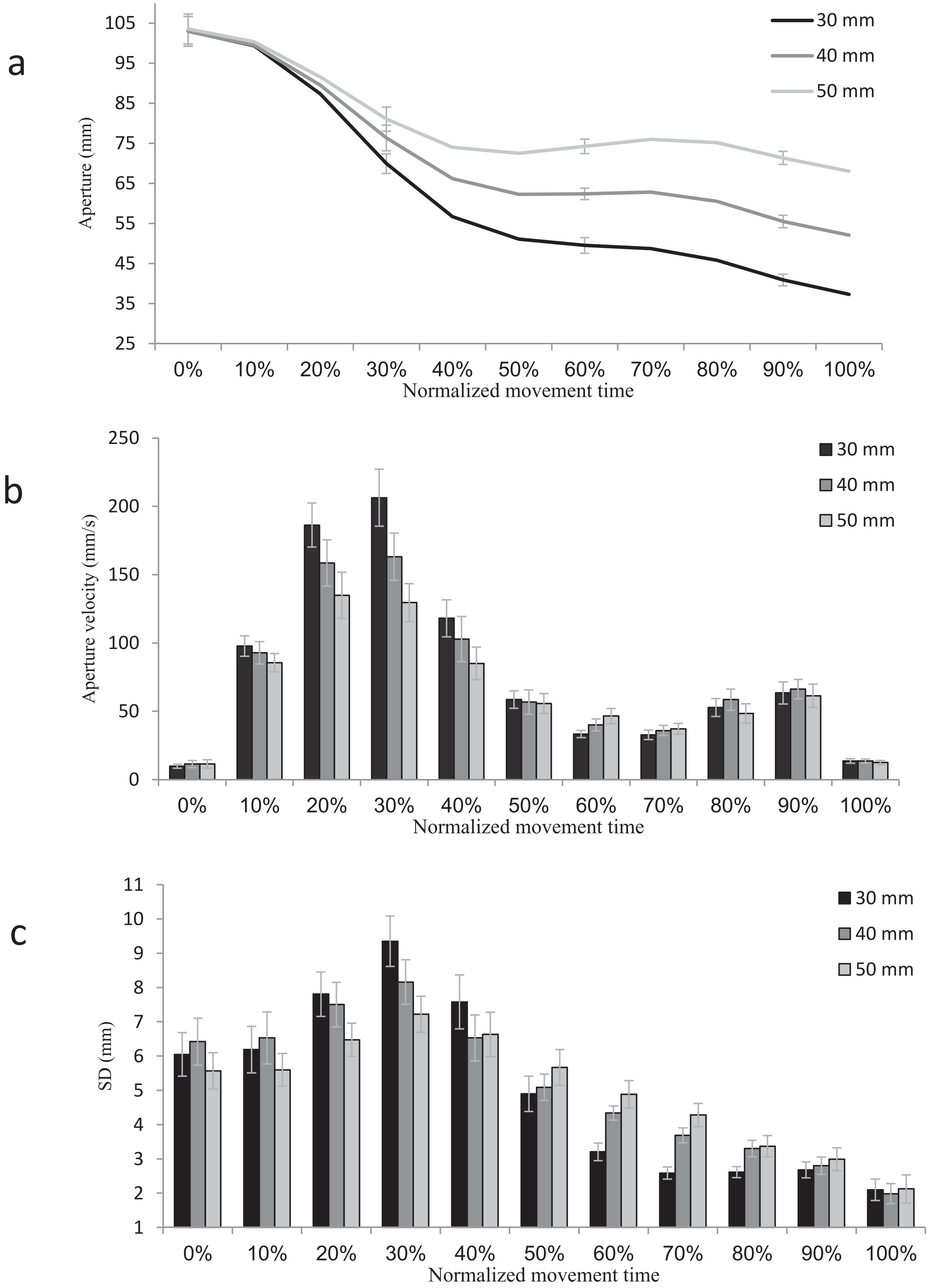

Figure 2. Movement trajectories in Experiment 1. (a) Average grip apertures, (b) aperture velocities, and (c) *SD*s (standard deviations of the aperture) throughout the movement trajectory. Note for the close correspondence between the velocity profile and the *SD* data. During early stages of the movement, aperture velocities were faster for smaller objects, a pattern which was also reflected by larger *SD*s. This pattern of relationships between *SD*s and object size is in the opposite direction to that predicted by Weber's law. Error bars denote standard errors of the mean.

the movement, participants reached a minimum aperture point and then started to open their fingers again prior to closing their fingers to grasp the object.

Finally and most importantly, *SD*s were calculated separately for each object using the standard deviation of the fingers' aperture. A repeated-measure ANOVA on *SD*s revealed a main effect of movement time, $F(10, 150) = 31.83$, $p < 0.001$, $\eta_p^2 = 0.68$. The main effect of object size was not significant, $F(2, 30) < 1$. A two way interaction between object size and movement time, $F(20, 300) = 7.62$, $p < 0.001$, $\eta_p^2 = 0.33$, indicated that *SD*s for different object sizes showed a different pattern of relationship at different parts of the movement (Figure 2c). Most importantly, and in harmony with the velocity data, *SD*s at the initial stage of the movement (20%–30%) were larger for smaller objects, which is, of course, opposite to what Weber's law predicts and in line with our predictions. A significant reverse linear trend was observed, reflecting an increase in *SD*s for smaller objects, $F(1, 15) = 4.2$, $p = 0.05$; $F(1, 15) = 13.61$, $p < 0.01$ for the 20% and 30% time points, respectively. This finding provides direct evidence that the finger's velocity, and not Weber's law, mediated the pattern of the relationship between *SD*s and object sizes during early stages of the movement which was observed in previous studies (Heath et al., 2012; Heath et al., 2011). Interestingly, later throughout the movement (60%–80%) when participants reopened their fingers and velocity was again positivity correlated with object size, the *SD* analysis revealed a corresponding positive linear trend, with smaller objects yielding smaller *SD*s compared to bigger objects, $F(1, 15) = 16.36$, $p < 0.01$; $F(1, 15) = 23.34$, $p < 0.01$; $F(1, 15) = 5.47$, $p < 0.05$ for the 60%, 70%, and 80% time points, respectively. This finding further reinforces our suggestion of robust correlation between aperture velocity and standard deviations, with faster aperture velocities yielding larger standard deviations compared to the yield of slower aperture velocities.

Experiment 2

The results of Experiment 1 strongly suggest that the adherence to Weber's law in previous studies was confounded by the fingers' velocity rather than have reflected a genuine adherence to Weber's law. This is the first empirical demonstration of the reciprocal relationships between aperture velocity during grasping and between the aperture's standard deviations. The initial large opening between the fingers prior to movement notations encouraged participants in Experiment 1 to close their fingers faster to smaller as compared to bigger objects. Under these constrains, *SD*s were larger for smaller objects, a finding which is at odds with the predictions of Weber's law and in line with our predictions according to which velocity, not Weber's law, mediated the increase in *SD*s with object size during initial stages of the movement.

These results also suggest that due to the mutual association between velocity and *SD*, a proper way to test the effects of Weber's law on grasping would be in parts of the grasping trajectories in which velocity is not confounded by object size, and therefore would not potentially affect *SD*s. As we argued in the Introduction (see also Foster & Franz, 2013), the point in time in which MGA is achieved serves as an excellent marker for the (null) effects of object size on JNDs, because the aperture velocity in that point in time is zero and cannot affect the *SD*s. Nevertheless, the results of Experiment 1, that clearly show the pre-shaping of the fingers' initial aperture prior to grasp affects the relationship between velocity and object size, suggest that it is possible to cancel out the unwarranted effects of velocity by a proper manipulation of the initial apertures between the fingers prior to grasp. In Experiment 2, we manipulated the initial aperture between the fingers to equate aperture velocities between objects of different size. The results of Experiment 1 showed that larger differences between the initial finger's aperture and the size of the target object led to the faster aperture velocities during initial stages of the movement. In Experiment 2, we have used this pattern of results to reason that if the difference between the initial fingers' aperture and the target objects would be equated across object sizes, it would be possible to cancel out the effects of movement velocity on *SD*s during grasp. Such equation of the movement velocity would allow an unbiased and unconfounded investigation of the possible effects of Weber's law on grasping throughout the entire movement trajectory. To this end, we manipulated the initial aperture between the fingers so it would be perfectly correlated with the size of the target object (the initial aperture was always 10 mm smaller than the size of the target object). Based on our previous findings and based on the results of Experiment 1, we predicted that when the effects of aperture velocity will be canceled out, no effects of Weber's law would be evident throughout the entire movement trajectory.

Methods

Participants

Twelve undergraduate students took part in the experiment and received the equivalent of $5 for their participation.

Experimental procedure and design

The procedure and design were similar to those used in Experiment 1, with one exception: Prior to each trial, participants were asked to place their thumb and finger holding a disk (20, 30, or 40 mm in diameter, 10 mm in height) which served as a starting point. The diameter of the disc was pre-adjusted to be always 10 mm smaller than the size of the target object. Using this method, we have assured that the opening between the finger and thumb prior to each grasp is in perfect correlation with the size of the target object. In all other aspects the procedure was similar to the one used in Experiment 1.

Results and discussion

The aim of Experiment 2 was to unconfound the effect of velocity on *SD*s by keeping grasping velocities equal across different objects' sizes. This equation of the movement allowed us to test the effect of Weber's law along the entire grasping trajectory.

The initial point from which participants preformed the grasping was perfectly correlated with the target object size (see Methods). As can be seen in Figure 3a, this manipulation resulted in similar movement trajectories for objects regardless of their size. The analysis of aperture velocity showed a corresponding pattern of results, and no differences were observed in the velocity pattern of the different object sizes even during the initial stages of the grasping trajectories (Figure 3b). Accordingly, repeated-measure ANOVA showed a main effect of movement time, $F(2, 22) = 11.5$, $p < 0.01$, but no effects of object size, $F(2, 22) < 1.00$ and no interaction between object size and movement time, $F(20, 300) < 1$. These findings show that the experimental manipulation successfully equalized aperture velocity across different object sizes. Therefore, it is now possible to test whether grasping would be affected by Weber's law during the different stages of the movement trajectory.

The *SD* data were subjected to a repeated-measures ANOVA. The main effect of object size, $F(2, 22) = 1.7$, $p > 0.2$, and the interaction between object size and movement time, $F(20, 300) = 1.08$, $p > 0.2$, were both nonsignificant. As for the velocity data, the main effect of movement time was again significant, $F(2, 22) = 11.5$, $p < 0.01$. Planned comparisons failed to find a linear trend for object size in any of the time points (all ps $>$ 0.1). Taken together, the results of Experiment 2 show that when velocity is controlled, there is no evidence of the effects of Weber's law throughout the movement trajectory.

General discussion

There is growing evidence suggesting that unlike visual perception, visually-guided grasping can be immune to the effects of Weber's law, one of the fundamental laws of visual perception (Ganel, Chajut, & Algom, et al., 2008; Ganel, Chajut, Tanzer, et al., 2008; Hadad et al., 2012; Holmes & Heath, 2013). Yet, there is a current debate on whether or not Weber's law can affect initial stages of the movement trajectories (Foster & Franz, 2013; Heath et al., 2012; Heath et al., 2011; Holmes et al., 2011). The results of the current study strongly suggest that the results of previous studies that argued that early grasping stages are affected by Weber's law were confounded by size-related movement effects of aperture velocity (Experiment 1). When velocity was controlled-for (Experiment 2), no effects of Weber's law were found throughout the movement, even during the early stages of the movement trajectories.

According to Weber's law, visual resolution should decrease for bigger compared to smaller objects. Visual resolution in the current study and in other relevant studies (Ganel, Chajut, & Algom, 2008; Ganel, Chajut, Tanzer, et al., 2008; Hadad et al., 2012; Heath et al., 2012; Heath et al., 2011; Holmes & Heath, 2013; Holmes et al., 2013; Holmes et al., 2011) was measured by the classic Method of Adjustment, in which the variance of the within-subject response (e.g., the standard deviation of the mean) is used as an effective measure that represents JNDs. The results of the current study show that when participants are encouraged to open their fingers faster, the variance of the response increases, probably as a result of a speed-accuracy tradeoff. In virtually all previous grasping studies which have addressed this question, participants were asked to keep their fingers closed together prior to grasp. This setup encouraged them to open their fingers faster to bigger objects during early stages of the movement. In turn, this pattern of aperture velocity resulted in greater variance values (*SD*s) for bigger compared to smaller objects. Although this pattern of results (increased variance with an increase in size) could be interpreted as an indication to the influence of Weber's law, the findings of the current study suggest that it merely reflects the relationships between *velocity and variance*, rather than the relationships between *object size and variance*. The results of Experiment 1 show, for example, that when object size is inversely correlated with the fingers' velocity, larger variance is found for smaller compared to bigger objects, which is in the opposite direction from that predicted by Weber's law. Our findings also suggest that when response variance serves as the main dependent variable of interest, researchers must be cautious as to unwarranted effects of variables such as velocity on their results. In Experiment 2, we used these insights to control for the effects of fingers' velocity, a condition which allowed an unbiased measurement of the relationships between object size

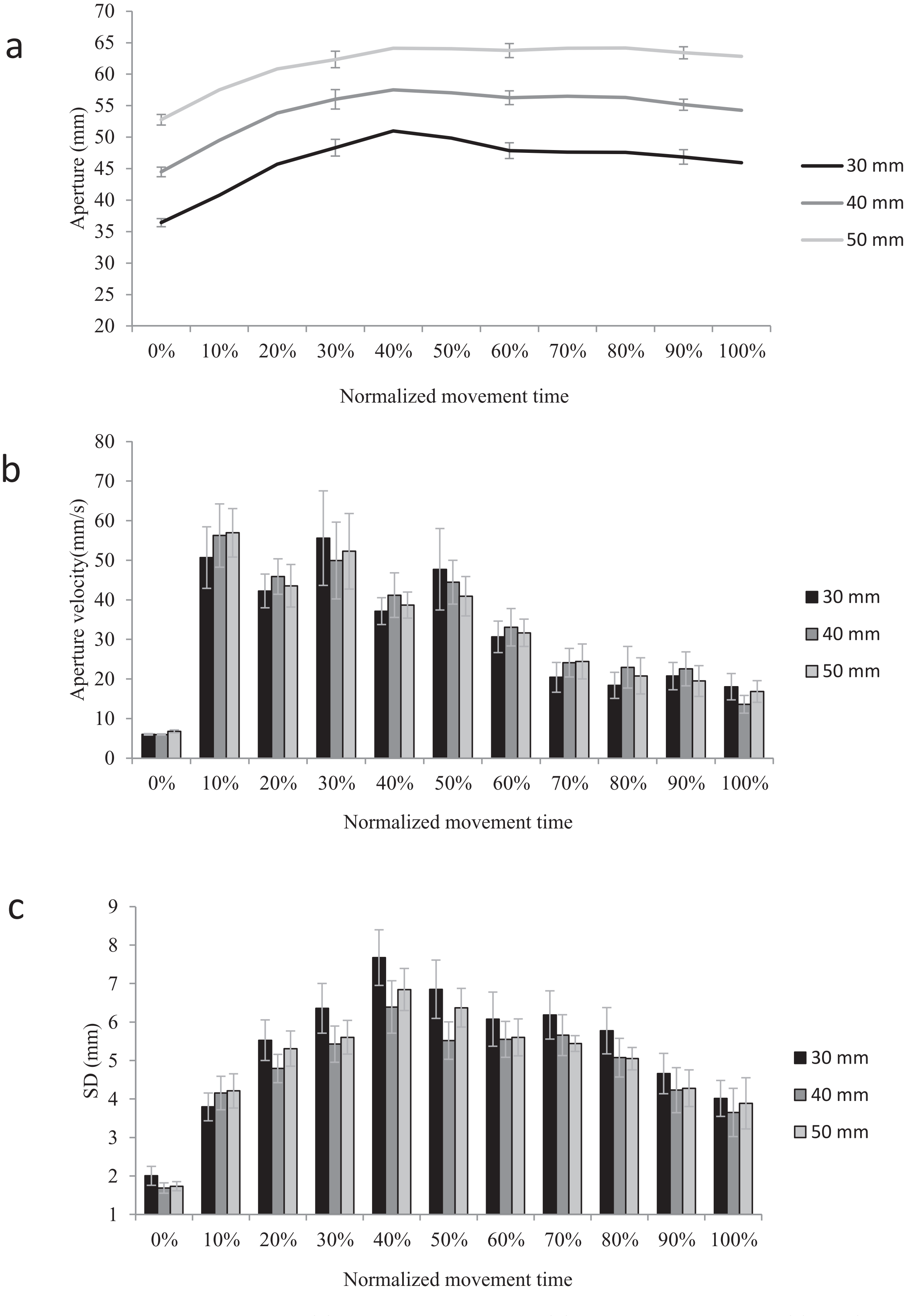

Figure 3. Movement trajectories in Experiment 2. (a) Average grip apertures, (b) aperture velocities, and (c) *SD*s (standard deviations of the aperture) throughout the movement trajectory. Movement trajectories and movement velocities were now similar across different object sizes. No effects of Weber's law were found throughout the entire movement trajectory. Error bars denote standard errors of the mean.

and visual resolution throughout the movement trajectory.

Recently, two studies that looked at the movement trajectories during perceptual manual estimations and during grasping directed to 2D rather than 3D objects revealed that JNDs during late stages of such movements were affected by Weber's law (Holmes & Heath, 2013; Holmes et al., 2013). Critically, as can be learned from the velocity profile in Experiments 1 and 2, the aperture velocity does not increase with object size during these final stages of the movement, so it is unlikely that JNDs were confounded by velocity during these stages. It can therefore be argued that unlike for grasping trajectories, perceptual estimates of object size or grasping trajectories toward 2D objects adhere to Weber's law.

In their commentary on Ganel, Chajut, and Algom's (2008) paper, Smeets and Brenner (2008) provide an alternative account for why grasping is immune to Weber's law. According to their account, the movement of each of the fingers is independently directed to different locations on the target object. According to this account, object size is not represented for grasping, but only its location. Therefore, according to Smeets and Brenner's account, due to the fact that location, unlike size, is a discrete (rather than continuous) dimension, Weber's law should not apply for grasping. Although Smeets and Brenner's interpretation is appealing and can account for why Weber's law does not affect grasping throughout the entire movement, several lines of evidence suggest that fingers' trajectories during grasping are tuned to object size and to magnitude in general, rather than to its location only. First, the results of a recent study by Holmes and Heath (2013), discussed earlier, showed that when participants are asked to direct their finger and thumb to grasp two dimensional rather than real, three dimensional objects, their grasping trajectories are affected by Weber's law throughout most of the movement trajectory. These findings cannot be accommodated by Smeets and Brenner's "dual-pointing" account that does not include representation of size because according to Smeets and Brenner's model, movements towards 2d objects, just as movements toward 3d objects, should be refractory to Weber's law. In addition, other evidence show that when participants are asked to base their grasping on memory representations of the target object, rather than on direct vision, their grip aperture is affected by Weber's law (Ganel, Chajut, & Algom, 2008). Again, these findings cannot be accommodated by a simple account of object position that does not take size into consideration. Finally, several studies showed that semantic and numerically-based magnitude information affects grasping trajectories during visuomotor control (Andres, Ostry, Nicol, & Paus, 2008; Glover, Rosenbaum, Graham, & Dixon, 2004). In particular, it has been shown that numbers with higher magnitude embedded on the object lead to larger grip apertures compared to number with smaller magnitudes. Recent findings from our lab also suggest that these effects are automatic in nature (Namdar, Tzelgov, Algom, & Ganel, in press). The findings that magnitude affects grip aperture also cannot be easily accommodated by location-based grasping models. We therefore conclude that although the idea that grasping trajectories are based solely on the location rather than the size of the target object seems to be appealing at first glance, several lines of evidence suggest that object size is indeed represented during grasping.

Weber's law is one of the fundamental principles governing human perception and cognition, and reflects a relative, rather than an absolute processing style of object size. Other examples of relative processing of size include the powerful effects of basic Gestalt principles of object shape on perceptual performance (Ben-Shalom & Ganel, 2012). The findings that visually-guided actions can be immune to the effects of Weber's law suggest that our perceptual representations of objects are organized in a fundamentally different way from the way visual information is processed for action. These results are also in line with previous evidence suggesting the visual perception of objects and their relations tends to be more holistic and contextual in nature, whereas the visual control action can be described as more veridical and analytic in nature (Ganel & Goodale, 2003; Goodale, 2011; Milne et al., 2013, but see also Hesse & Schenk, 2013). Therefore, basic psychophysical features that characterize perceptual measurements of performance do not necessarily characterize the processes that mediate visuomotor control. Future research, aimed at the psychophysical elements of visuomotor control, would help unraveling potential dissociations, as well as important similarities between the way vision guides our actions and our perception of the world.

Keywords: action, perception, Weber's law

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