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RESEARCH ARTICLE

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Manual size estimation: a neuropsychological measure of perception?

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Abstract Manual size estimation (participants indicate the size of an object with index finger and thumb) is often interpreted as a measure of perceptual size information in the visual system, in contrast to size information used by the motor system in visually guided grasping. Because manual estimation is a relatively new measure, I compared it to a more traditional perceptual measure (method of adjustment). Manual estimation showed larger effects of the Ebbinghaus (or Titchener) illusion than the traditional perceptual measure. This inconsistency can be resolved by taking into account that manual estimation is also unusually responsive to a physical variation of size. If we correct for the effect of physical size, manual estimation and the traditional perceptual measure show similar illusion effects. Most interestingly, the corrected illusion effects are also similar to the illusion effects found in grasping. This suggests that the same neuronal signals which generate the illusion in the traditional perceptual measure are also responsible for the effects of the illusion on manual estimation and on grasping.

Keywords Motor control · Visual pathways · Illusions · Prehension · Human

Introduction

Current neuroscience has a strong interest in the question whether visual awareness (or "perception") is generated by similar processes and brain areas to visually guided motor behavior. According to the prominent view of Milner and Goodale (1995), different processes generate visual perception from visually guided actions. Strong evidence for this perception-versus-action hypothesis is the finding that visual size-contrast illusions affect perception to a much larger extent than grasping (Aglioti et al. 1995). However, this finding is highly controversial and is still hotly discussed (Pavani et al. 1999; Franz et al. 2000; Carey 2001; Smeets and Brenner 2001; Franz 2001; Bruno 2001; Haffenden et al. 2001; Plodowski and Jackson 2001; Glover 2002).

Reviewing the literature on this topic yields an interesting and unexpected result (Franz 2001): Studies which report larger perceptual than motor effects of visual illusions tend to employ a different perceptual measure than studies which find equal effects of visual illusions on perception and on grasping.

On the one hand, studies which found that the Ebbinghaus–Titchener illusion (Fig. 1a) affects grasping to the same extent as perception used "traditional" perceptual tasks to assess the illusion effect: For example, in the study of Pavani et al. 1999, participants judged whether a comparison stimulus was of the same size as the central element of the Ebbinghaus figure. Similarly, in the study of Franz et al. 2000, participants adjusted a comparison stimulus to match the size of the central element of the Ebbinghaus figure.

On the other hand, studies which found larger illusions effects on perception than on grasping typically used a measure for perception which has often been called "manual estimation": Participants indicated the size of the central element of the Ebbinghaus figure by using index finger and thumb. In some studies they had full vision of hand and stimulus during estimation (Daprati and Gentilucci 1997); in other studies they had no vision of hand and stimulus during the estimation (Haffenden and Goodale 1998). Since these initial studies, a large number of studies used manual estimation as a measure for the perceptual effects of visual illusions and found larger illusion effects on manual estimation than on grasping (Daprati and Gentilucci 1997; Haffenden and Goodale 1998; Otto de Haart et al. 1999; Westwood et al. 2000a, 2000b, 2001; Haffenden et al. 2001; Bartelt and Darling 2002).

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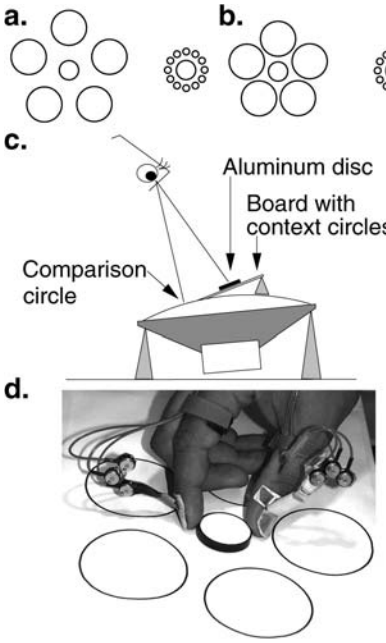

Fig. 1 a The Ebbinghaus (or Titchener) illusion in its standard form: A circle surrounded by larger circles is perceived as being smaller than if surrounded by smaller circles (and vice versa). The illusion is strongest if the small context circles are relatively close to the central circle and the large context circles are relatively far from the central circle (Girgus et al. 1972). **b** Variant of the Ebbinghaus illusion used in this study: To control for possible effects of the distance of the context circles on grasping (cf. Haffenden et al. 2001), the distance of the large context circles was matched to the distance of the small context circles. **c** Apparatus used in this study: Participants viewed a board with the context circles drawn on it. In the center of the context circles an aluminum disc was positioned. In the grasping task, participants grasped the disc. In the manual estimation task, they indicated the size of the disc using index finger and thumb. In the adjustment task, they adjusted a comparison circle displayed on the monitor to match the size of the disc. **d** A participant grasping the aluminum disc

In this situation, the question arises of which perceptual measure is most appropriate to be compared to grasping: Manual estimation or the more traditional perceptual measures? Interestingly, none of the existing studies performed a comparison between manual estimation and the traditional perceptual measures such as, for example: method of adjustment, method of constant stimuli, and comparison methods (cf. Coren and Girgus 1972). Given the increasing use of manual estimation also in more general fields of the cognitive neurosciences (Haffenden and Goodale 2000b; Westwood et al. 2002), it seems beneficial to assess its outcomes in relation to traditional perceptual measures. If manual estimation shows a similar pattern of results to the traditional perceptual measures, then we can be more reassured that all these perceptual measures are comparable. On the other hand, if there are systematic deviations between manual estimation and the traditional perceptual measures, then we have to find an explanation for these deviations before we can use one or the other of these measures for inferences about the underlying brain processes.

The goal of this study was to perform a comparison between the effects of the Ebbinghaus illusion on manual estimation, on grasping, and on traditional perceptual measures. Special care was taken to match the conditions between the different tasks as well as possible. For example, the distance between the context elements and the central element of the Ebbinghaus illusion was equal in the two illusion conditions (Fig. 1b). This was done because a different gap between context elements and central element might selectively affect grasping and could lead to artificial illusion effects in grasping (as suggested by Haffenden et al. 2001; but see Franz et al. 2003). Also, the responsiveness of each of the measures to a *physical* variation of size was assessed. This is an important baseline condition which gives us the possibility to predict the expected responsiveness of the measure to an *illusionary* variation of size by taking into account the slopes of the linear functions which relate the measures to physical size. To see this, consider two measures, one which responds to a physical change in size of 1 mm with an increase of, say, 5 mm, while the other responds with an increase of only 2 mm. Assuming under the null hypothesis that an illusory size change has a similar effect to a physical size change on a single, internal size estimate, one would expect a relationship of 5:2 also for the illusion effects (cf. Franz et al. 2001).

The experiment consisted of three tasks: manual estimation, an adjustment task (as traditional perceptual measure), and grasping. The effects of the Ebbinghaus illusion and of a physical variation of size were assessed for each of the tasks and compared. Of special interest was: (a) whether grasping is affected by the illusion; (b) if so, whether the illusion effects on grasping are smaller than the illusion effect for the other two measures; and (c) whether manual estimation shows similar illusion effects to the adjustment task.

Methods

Participants

Twenty-eight volunteers (15 female, 13 male) participated in the experiment, ranging in age from 15 to 38 years (mean: 25.1 years, SD: 5.6 years). In return for their participation, they received a payment of 15 DM/h (approximately 7.5 €, or 7 US$). Participants had normal or corrected-to-normal vision (Snellen-equivalent of 20/25 or better; Ferris et al. 1982), normal stereopsis of 60 s of arc or better (Stereotest circles; Stereo Optical, Chicago), and were right-handed (Oldfield 1971). Written, informed consent was obtained from the participants prior to their inclusion in the study, and the rights of the participants were protected according to the 1964 Declaration of Helsinki.

Stimuli

The stimuli are shown in Fig. 1b. The large and small context circles were 58 mm and 10 mm in diameter, respectively. For both sizes of the context circles, the distance between the midpoint of the target disc and the nearest point on the context circles was 24 mm (these conditions are geometrically identical to the "Large–Near" and "Small–Near" conditions used by Franz et al., 2003). All context circles were drawn on a board. The targets were aluminum discs, 31, 34, or 37 mm in diameter (corresponding to 2.7°, 3.0°, and 3.3° of visual angle) and 5 mm in height. To maximize the similarity between the three-dimensional target disc and the two-dimensional context circles, the shadows were minimized and participants viewed the stimuli from above.

In the adjustment task, an isolated comparison circle was displayed on a computer monitor at a distance of 155 mm (13.8° of visual angle) from the target disc. The comparison was offset in the midsagittal plane of the participant such that it was closer to the participant's body than the target disc. The distance between eye and target disc was the same as the distance between eye and comparison circle (approx. 65 cm).

Apparatus

The apparatus is shown in Fig. 1c. Participants sat on a stool and used a chin rest to keep the position of the head constant. They looked down at a 21-inch monitor (effective screen diagonal of 48.5 cm) as if looking at the top of a table. The monitor was positioned at a distance of approximately 65 cm from the eyes. The screen of the monitor served as a table for the presentation of the stimuli. The screen was not horizontal, but tilted to be oriented perpendicular to gaze direction. Participants wore liquid-crystal (LC) shutter glasses (Milgram 1987) which allow efficient suppression of vision. The trajectories of the finger movements were recorded using an Optotrak system (sampling rate 100 Hz). Six infrared light-emitting diodes (LEDs) were mounted on two little flags (three LEDs per flag). The flags were attached to thumb and index finger (cf. Fig. 1d). Before the experiment started, the typical grasp points on the fingers were determined and measured relative to the markers on the flags. This enabled me to calculate the trajectories of the grasp points and to determine in the grasping task the MGA (i.e., the maximum aperture between index finger and thumb during the reach phase of the grasp movement), as well as the indicated size in the manual estimation task.

Procedure

In the grasping task, participants grasped the target disc with their dominant, right hand, lifted the disc, and deposited it at the side of the monitor. Then, the experimenter re-collected the target disc and prepared the next trial. The LC shutter glasses suppressed vision as soon as the midpoint between the fingers had moved at least 20 mm away from their resting position (on average 661±37 ms after stimulus presentation) such that participants could neither see their hand nor the stimulus during grasping. The distance between resting position of the hand and the target disc was 27 cm. Participants were allowed 2.5 s for the grasping movement (from opening of the shutter glasses until having moved the disc at least 20 mm away from its position). If this time limit was exceeded, the trial was pushed back to the set of trials to be performed and repeated at a random, later time. As in the other tasks, trials were presented in a random order. Each participant performed 42 grasps (3 sizes of the central disc × 2 illusion conditions × 7 repetitions).

The manual estimation task was very similar to the grasping task, except that participants indicated the size of the target disc with index finger and thumb prior to grasping: they lifted their right, dominant hand and indicated the size of the target disc using index finger and thumb. When they felt that they showed the correct size, they indicated this by pressing a mouse-button with their left hand. After this, participants grasped the target disc (this was done to provide them with the same amount of haptic feedback as in the grasping task). As in the grasping task, the LC shutter glasses suppressed vision as soon as the fingers had moved at least 20 mm from their resting position (on average 871±38 ms after stimulus presentation), such that the participants did the manual estimation as well as the subsequent grasping without vision. Participants were allowed 2.5 s to complete the manual estimation (from opening of the shutter glasses until having pressed the mouse button with the left hand). They were allowed a relative velocity between index finger and thumb of maximal 30 mm/s at the time of the manual estimation. If this velocity or the time limit were exceeded, the trial was pushed back to the set of trials to be performed and repeated at a random, later time. As in the other tasks, trials were presented in a random order. Each participants performed 42 manual estimations (3 sizes of the central disc × 2 illusion conditions × 7 repetitions).

In the adjustment task, participants used the buttons of a computer mouse to adjust the isolated circle, which was displayed on the computer monitor until they perceived it to be of the same diameter as the target disc. The initial diameter of the comparison circle was set randomly between 17 and 48 mm (step sizes of 1 mm, uniform distribution). During the adjustments, participants had full vision of the stimuli and there was no time limit for the adjustments. In perceptual control experiments, I had established that this adjustment method leads to the same measured illusion effects as a constant stimuli method with 800 ms presentation time (see also Franz et al. 2000, for further control experiments). The adjustment method has the advantage of being more efficient. The LC shutter glasses suppressed vision as soon as the participant finished the adjustments and until the next trial was set up by the experimenter. For each participant the trials were presented in a different computer-generated, random order. Each participant performed 18 adjustments (3 sizes of the central disc × 2 illusion conditions × 3 repetitions).

All tasks were performed in separate blocks, with the succession of the tasks being counterbalanced between participants. In all tasks, the experimenter prepared each trial according to the computer-generated, random order, selected the current combination of context circles and target disc, positioned the target disc on top of the board with the context circles, and mounted the board on top of the monitor. The LC shutter glasses were opaque during this preparation. When the preparation was finished, the experimenter pressed a button to open the LC shutter glasses and to start the trial.

Data analysis

For data analysis, repeated-measures ANOVAs were calculated with the factors Size of target disc (3 levels: 31, 34, 37 mm) and Illusion (2 levels; see Fig. 1b). Dependent variables were MGA (grasping task), adjusted size of the comparison circle (adjustment task), and the indicated size between index finger and thumb (manual estimation task).

For each dependent measure, the corrected illusion effect was calculated. The corrected illusion effect takes into account the slope of the linear function which relates the dependent measures to physical size (see the Introduction). In principle, the correction could be fairly easy: simply divide the illusion effect by the slope (for a detailed discussion and mathematical formulation, see Franz et al. 2001). However, we also need to estimate the variability of the corrected illusion effects. This is not trivial, because we have to take into account the variability of the measured illusion effects as well as the variability of the measured slopes. Because the slope is in the denominator, the correction can lead to serious mathematical problems. For example, consider the case that the confidence interval of the slope contained zero (or values close to zero). In this case, the corrected illusion effect can become arbitrarily large (or small), with arbitrarily large variability.

Some recent studies also had to solve this problem (Glover and Dixon 2001, 2002; Haffenden et al. 2001; Franz 2003) and took different, more or less ad-hoc approaches to estimate the variability of the corrected illusion effects. Here, I utilized a statistical approach which was developed especially for this problem and is usually called "Fieller's theorem" (Fieller 1932, 1954): Let x and y be two normally distributed random variables, then Fieller's theorem gives exact confidence limits for the ratio $y{:}x$. The exact formulas for the calculation are described by Fieller (1954).

A significance level of $\alpha=0.05$ was used for all statistical analyses. *P*-values above 0.001 are given as exact values. For parameters which are given as $x \pm y$, x is the mean and y is the standard error of the mean.

Results

Results of all experimental conditions are shown in Fig. 2. In all tasks the main effects of the illusion as well as of the physical size of the target disc were highly significant (see Table 1).

The mean illusion effects are shown in Fig. 3a. Comparing the illusion effects between the different tasks shows that manual estimation yielded a larger illusion effect than both the adjustment task [$t(27)=5.18$, $P<0.001$] and grasping [$t(27)=2.17$, $P=0.04$]. On the other hand, the adjustment task and grasping did not differ significantly in their illusion effects [$t(27)=1.84$, $P=0.08$].

Though not statistically significant, grasping seems to show a slightly *larger* illusion effect than the adjustment task. To assess whether this is a substantial effect or only due to random statistical fluctuations, we can compare the results with the data of a previous study (Franz et al. 2003), in which the same conditions were used for grasping and the adjustment task with a very large sample size (52 participants). Figure 3b shows the illusion effects found by Franz et al. (2003) for these conditions. Comparing the illusion effects suggests that indeed the slightly larger grasp effect seems due to random statistical fluctuations. This is also confirmed by an ANOVA on the illusion effects with the factors task (2 levels: adjustment task versus grasping) and study (2 levels: this study versus that of Franz et al. (2003). The ANOVA shows no difference of the illusion effects between grasping and the adjustment task ($F_{1,\ 78}=2.05$, $P=0.16$). Also there was no difference of the illusion effects between studies, nor was there a task × study interaction (both $P>0.26$).

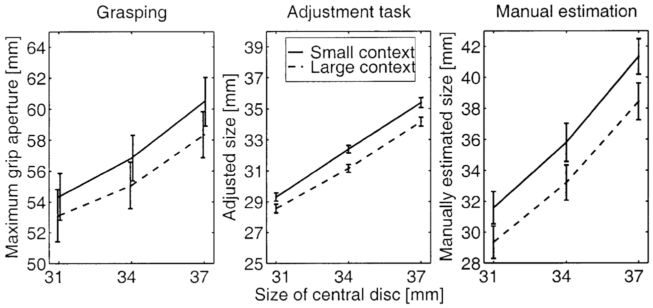

Fig. 2 Results of grasping, the adjustment task, and of manual estimation: Mean MGA (grasping), mean adjusted size of the comparison (adjustment task), and mean indicated size (manual estimation) as functions of the diameter of the target disc and of the illusion-inducing context. *Error bars* depict ±1 standard error of the mean. Note that the standard errors contain between-subjects variability, which is not relevant for the statistical tests of the illusion effects

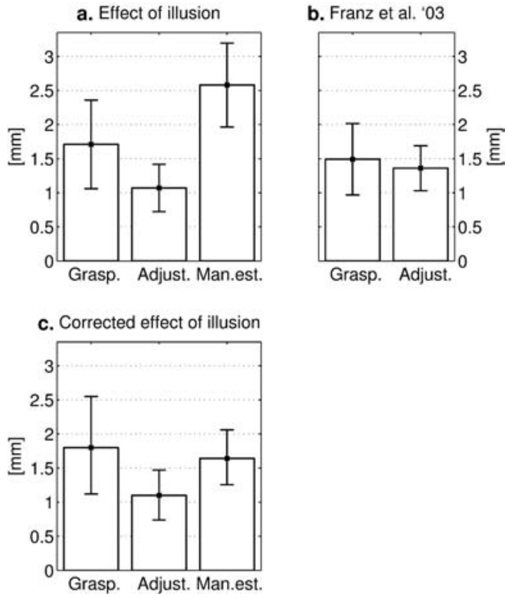

Fig. 3 **a** Overall illusion effects for grasping, the adjustment task, and manual estimation, averaged across all sizes of the target disc. **b** The illusion effects for grasping and the adjustment task, as measured by Franz et al. (2003) under conditions identical to the conditions used in this study and with a large sample size of 52 participants. **c** Corrected illusion effects. Each illusion effect is corrected by the slope which relates the dependent measure to physical size (cf. Table 2). *Error bars* depict 95% confidence intervals

Table 1 ANOVAs for grasping, the adjustment task, and manual estimation. For each task, an individual repeated-measures ANOVA was calculated. Factors were illusion (large versus small context circles) and size of the target disc (diameters: 31, 34, 37 mm). Dependent variables were MGA (the maximum aperture between index finger and thumb during the reach phase of the grasping task), adjusted size of the comparison circle (adjustment task), and the indicated size using index finger and thumb (manual estimation)

	Main effect Illusion		Main effect Size of target disc		Interaction Illusion × size	
Task	$F_{1,\ 27}$	*P*	$F_{2,\ 54}$	*P*	$F_{2,\ 54}$	*P*
Grasping	29.2	<0.001***	108.4	<0.001***	1.3	0.28
Adjustment task	40.0	<0.001***	517.9	<0.001***	1.8	0.18
Manual estimation	73.8	<0.001***	233.5	<0.001***	0.6	0.58

*$P<0.05$; **$P<0.01$; ***$P<0.001$

Table 2 Illusion effects, slopes, and corrected illusion effects for all tasks. Summary of the illusion effects, slopes, and corrected illusion effects, as shown in Figs. 2and 3

	Illusion effect		Slope		Corrected illusion effect	
		95% CI		95% CI		95% CI
Grasping	1.71	1.06–2.35	0.95	0.80–1.10	1.80	1.12–2.55
Adjustment task	1.07	0.72–1.42	0.97	0.90–1.04	1.10	0.74–1.47
Manual estimation	2.58	1.96–3.20	1.57	1.39–1.74	1.64	1.26–2.06

Correction for different slopes

Inspecting Fig. 2 shows that manual estimation yielded not only a larger illusion effect than the adjustment task and grasping but also a larger slope. As argued in the Introduction and by Franz et al. (2001), this situation requests that we correct the illusion effects for the slopes which relate the measures to physical size. The correction consists (essentially) in dividing the illusion effect by the slope (for details on the correction and the nontrivial estimation of the variability of the corrected values, see the Methods section).

Figure 3c shows the corrected illusion effects and Table 2 gives a detailed summary of all relevant parameters. After correction the differences between the perceptual measures were much smaller. Most interestingly, manual estimation now shows a similar illusion effect not only to the adjustment task, but also to grasping.

Discussion

The Ebbinghaus illusion affected grasping, the adjustment task (a traditional perceptual measure), and manual estimation (which has been interpreted as an alternative way to measure perception). Before correction, the illusion effect was larger in manual estimation than in the adjustment task and in grasping, while the adjustment task and grasping did not differ in their illusion effects.

These results replicate in one single experiment most of the literature on a possible dissociation between perception and action in the Ebbinghaus illusion: (a) as in earlier studies, there was no difference between the illusion effects in the traditional perceptual measure and grasping (Pavani et al. 1999; Franz et al. 2000); (b) this was true, despite the fact that the distance between context elements and central disc was matched for the two illusion conditions to avoid possible artifactual effects on grasping (as suggested by Haffenden and Goodale 2000a; Haffenden et al. 2001)—a finding which replicates that of Franz et al. (2003); (c) manual estimation showed a larger illusion effect than grasping, as in previous studies (Daprati and Gentilucci 1997; Haffenden and Goodale 1998; Haffenden et al. 2001).

However, manual estimation showed illusion effects larger not only than grasping, but also than the traditional perceptual measure. This inconsistency seems responsible for the contradictory results which have been reported by the different research groups in recent years, because some groups used (exclusively) manual estimation, while other groups used (exclusively) traditional perceptual measures.

If this were the whole story, it would be difficult to interpret these results. One possibility would be to decide that manual estimation is the appropriate perceptual measure for the comparison to grasping. In this case we would conclude that there is indeed a dissociation between perception and action in the Ebbinghaus illusion. The other possibility would be to prefer the traditional perceptual measures and in consequence we would conclude that there is no dissociation between perception and action in the Ebbinghaus illusion. A third possibility would be to postulate an additional dissociation within the perceptual system: between traditional perceptual measures on the one hand and manual estimation on the other. From a theoretical point of view, these three possible solutions are not very convincing. They are quite ad hoc and not very parsimonious. A fourth possibility would be that the different tasks rely on different aspects of the visual information. For example, Smeets et al. (2002) convincingly showed that a number of dissociation phenomena can nicely be explained by the use of different spatial attributes (for example, position and size) if different tasks have to be performed on the same stimuli. However, in the case of manual estimation and traditional perceptual measures, it is not clear what these different spatial attributes should be. It seems plausible that in both tasks size (and not, for example, position) is used.

Fortunately, the analysis of the slopes which relate physical size to the different perceptual and motor measures solves these problems and leads to a very simple and coherent picture. The slopes reveal that manual estimation is unusually responsive to variations of physical size. If we correct the illusion effects for the slopes, we find similar effects of the Ebbinghaus illusion in manual estimation, in the traditional perceptual measure, and in grasping.

How does this result relate to the literature? Only one earlier study (Haffenden et al. 2001) performed a similar correction for manual estimation. Interestingly, the slope of manual estimation (1.85±0.43) was very similar to the slope found in this study (Table 2). However, the corrected effect of the Ebbinghaus illusion on manual estimation was still larger than the corrected effect on grasping. Future research should clarify which of these results is more reliable (see also Franz et al. 2003 for a further discussion of Haffenden et al. 2001). Unfortunately, Haffenden et al. (2001) did not employ a traditional perceptual measure for comparison, which might have helped to clarify the different results.

Given the fact that manual estimation shows a larger slope in relation to physical size than traditional perceptual measures and grasping, we always need to correct for the slopes if we want to perform comparisons between these different tasks. Unfortunately, most of the studies that compared illusion effects on manual estimation with illusion effects on grasping did not perform this correction (for an overview, see Franz 2001). Therefore, these studies are not really conclusive, because even if the grasp effects of the illusion were based on the same internal size information as the effects on manual estimation, you would still observe a larger illusion effect in manual estimation than in grasping.

It is interesting to speculate why manual estimation is so responsive to a (physical or illusionary) variation of size. One reason might be that in this study (as well as in most other studies) no visual feedback of the hand was allowed during performance of the task. Participants had to rely exclusively on proprioceptive feedback. It is likely that proprioceptive information is not as accurate as visual information and therefore participants might exaggerate their response (thanks to Anne-Marie Brouwer for pointing this out).

This reasoning also shows that the interpretation of manual estimation as a *perceptual* measure is not as obvious as has often been assumed: While indicating the size of an object with index finger and thumb (without seeing the hand), participants must use proprioceptive cues and employ a number of motor processes. It is not clear why these motor processes should not affect the outcome of the measure (see Pavani et al. 1999). In fact, some authors used measures similar to manual estimation to assess motor effects of visual illusions (Vishton et al. 1999) or to investigate more general aspects of the visuomotor transformation (Jeannerod and Decety 1990).

Conclusions

Traditional perceptual measures and manual estimation (which is often also interpreted as a perceptual measure) lead to inconsistent results for the perceptual effect of the Ebbinghaus illusion. If, however, we correct for the slopes which relate these measures to physical size, then we obtain similar estimates for the size of the perceptual illusion. In addition, the corrected illusion effects correspond well to the illusion effects found in grasping. If this result proves reliable (for a different outcome, see Haffenden et al. 2001), it suggests that the same neuronal signals are responsible for the illusion in the traditional perceptual measures, in manual estimation, and in grasping (cf. Pavani et al. 1999; Franz et al. 2000).

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