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Planning versus online control: dynamic illusion effects in grasping?

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Abstract—The planning/control model of action assumes that grasping is sensitive to the context of an object only in early stages of the movement (planning), but not in later stages (control). In consequence, the effects of context-induced illusions (such as the Ebbinghaus/Titchener illusion) should decrease during a grasping movement. Here, we tested this claim by reanalysing a large data set ($N = 26$) on grasping in the Ebbinghaus illusion. Contrary to the predictions of the planning/control model, we found that the effects of the illusion did not decrease over time. Instead, the illusion effects stayed remarkably constant.

Keywords: Visual illusions; grasping; planning; control.

INTRODUCTION

During recent years there has been vigorous discussion on the question of whether visual illusions, which depend on higher cognitive functions, affect motor actions to the same extent as perception. An example of such an illusion is the Ebbinghaus/Titchener illusion (cf. Fig. 1a). In this illusion, the size of contextual elements affects the perceived size of a central element. A number of studies suggest that this illusion is partially dependent on higher cognitive functions such as, for example, semantic similarity between the central element and the contextual elements (e.g. Coren and Enns, 1993; Zanuttini *et al.*, 1996; Deni and Brigner, 1997). The question of whether the Ebbinghaus illusion affects motor acts in the same way as perception has strong theoretical implications. If motor actions are largely refractory to the Ebbinghaus illusion (or to similar illusions), this would provide strong evidence for the notion that there exist two separate visual systems — one system which processes visual information to guide actions and a second system which creates a visual percept of the world (Goodale and Milner, 1992; Milner and Goodale,

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1995). A typical example of such a dissociation between perception and action was reported by Aglioti *et al.* (1995), who found that the Ebbinghaus illusion clearly affected perception but only marginally affected grasping. Note, however, that this finding is still highly controversial (for comments and reviews see: Snowden, 2000; Bruno, 2001; Carey, 2001; Franz, 2001; Plodowski and Jackson, 2001; Smeets and Brenner, 2001; Glover, 2002).

Recently, Glover and Dixon (2001a, b, 2002) suggested a different possibility for the relationship between the processing of visual information for motor actions and for perception. They proposed that only early stages of motor planning are affected by visual illusions, while later stages might be largely unaffected. This planning/control model of action assumes that the early stages (planning) operate in a context-dependent way and therefore are likely to be affected by illusion-inducing contextual elements such as are responsible for the Ebbinghaus illusion. Glover and Dixon assume that after the initial planning phase, actions are corrected online, using a context-independent representation. In consequence, this control phase should be largely immune to contextual illusions such as the Ebbinghaus illusion.

The planning/control model of Glover and Dixon (2001a) is a variant of a set of accounts which go back as far as to Woodworth (1899). In the version of Glover and Dixon the planning/control model is not fully compatible with the perception/action distinction as put forward by Milner and Goodale (1995). The reasons for this are: (a) The planning/control model assumes that actions are always guided by two representations — in early stages by a context-dependent representation, and in late stages by a context-independent representation. In contrast, the perception/action model assumes that actions are mainly guided by one representation which is context-independent. (b) According to the planning/control model, the buildup of a context-dependent representation in the planning stage precedes actions. This contradicts the notion of Milner and Goodale (1995) that the creation of a context-dependent representation is too slow to guide immediate actions.

The planning/control model is strongly based on Glover and Dixon's finding that early phases of motor actions (e.g. grasping) are more affected by visual illusions than later phases (Glover and Dixon, 2001a, b, 2002). However, some authors criticized this finding (Danckert *et al.*, 2002) and therefore further investigation of this topic seems needed. Here, the planning/control model is tested by reanalysing a large set of data on grasping in the Ebbinghaus illusion (Franz *et al.*, 2000).

Franz *et al.* (2000) replaced the central circle of the Ebbinghaus illusion by a disc which was grasped by the participants (cf. Fig. 1b). The grasp trajectories were measured and the effect of the illusion on grasping was evaluated and compared to the perceptual effect of the illusion. We reanalyzed these data in such a way that the effects of the illusion in early stages of the grasp movement can be compared to the effects of the illusion in late stages. For this, the time course of each grasp was normalized such that a normalized time of 0% corresponded to movement onset and a normalized time of 100% to the time of the maximum grip aperture

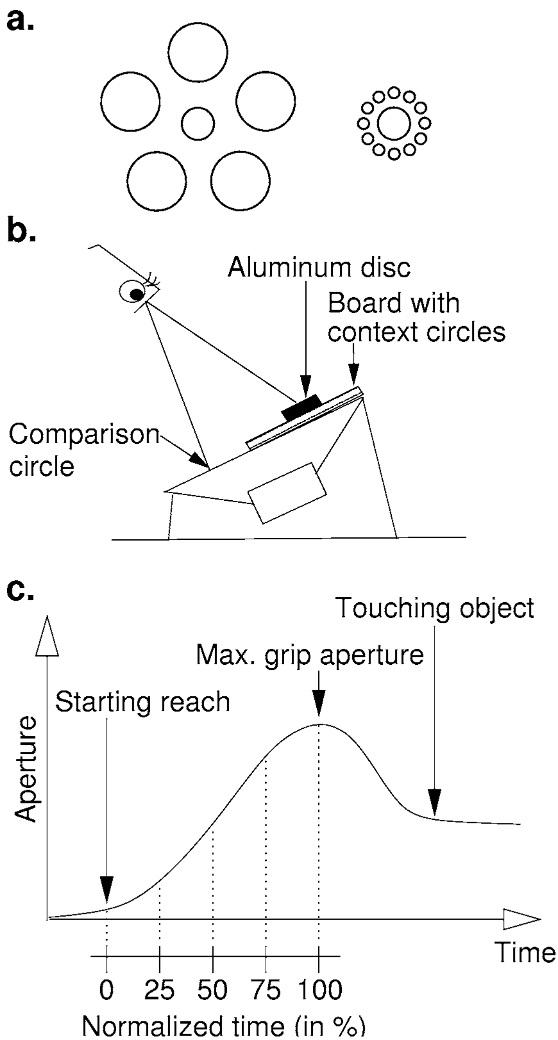

Figure 1. (a) The Ebbinghaus/Titchener illusion: A circle surrounded by larger circles is perceived as being smaller than if surrounded by smaller circles (and *vice versa*). The two Ebbinghaus figures are drawn approximately to scale to the stimuli used in Franz *et al.* (2000). (b) Apparatus used by Franz *et al.* (2000): 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 perceptual task, participants adjusted a comparison circle displayed on the monitor to match the size of the disc. (c) A prototypical grasp movement. Before the object is touched, the aperture between index finger and thumb reaches a maximum which is larger than the size of the object. This maximum grip aperture is linearly related to object size (Jeannerod, 1981, 1984). In the present study, the grip aperture was evaluated at different time points between movement onset (normalized time = 0%) and the time of the maximum grip aperture (normalized time = 100%).

(cf. Fig. 1c). Five different time points (0%, 25%, 50%, 75%, 100%) were chosen for the comparison. If the planning/control model is correct, then there should be larger illusion effects on grasping at early time points than at late time points.

METHODS

This experiment was already described in Franz *et al.* (2000). For clarity of presentation, the relevant points are repeated here and, where necessary, described in more depth than in Franz *et al.* (2000).

Participants

Twenty-six volunteers (14 female, 12 male) participated in the experiment, ranging in age from 18 to 35 years (mean: 24.7 years, SD: 4.5 years). In return for their participation, they received a payment of 13 DM per hour (approximately 6.5 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).

Stimuli

The stimuli are shown in Fig. 1a. The large (small) context elements were 5 (12) circles, 58 mm (10 mm) in diameter, the centers of the circles being 118 mm (60 mm) apart. All context circles were drawn on a board. The targets were aluminum discs, 28, 31, 34, or 37 mm in diameter (corresponding to 2.4, 2.7, 3.0, and 3.3 degrees of visual angle) and 5 mm in height. To maximize the similarity between the three-dimensional target disc and the two-dimensional context circles we minimized shadows and had participants view the stimuli from above. In the perceptual task, an isolated comparison circle was displayed on a computer monitor at a distance of 155 mm (13.8 degrees of visual angle) from the target disc.

Apparatus

The apparatus is shown in Fig. 1b. 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 table for the presentation of the stimuli. Participants wore liquid-crystal (LC) shutter glasses (Milgram, 1987) which allowed them to efficiently suppress 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. Before the start of the experiment, the typical grasp points on the fingers were determined and measured relative to the markers on the flags. This enabled us to calculate the trajectories of the grasp points and to determine the grip aperture as a function of time.

Procedure

In the grasping task, each trial was started when the LC shutter glasses opened such that the participant could see the stimuli. Between trials, the participants rested their dominant, right hand at a distance of 27 cm from the target disc. After the LC shutter glasses opened, participants grasped the target disc, lifted it, and deposited it at a convenient position at the side of the apparatus. The LC shutter glasses suppressed vision as soon as the fingers had moved at least 20 mm from their resting position (on average 825 ± 61 ms after stimulus presentation; this corresponds to 44 ± 8 ms after movement onset, as defined below) such that participants could neither see their hand nor the stimulus during grasping. Participants were instructed to grasp as naturally and normally as possible. Participants had 4 seconds to complete the grasp (from opening of the shutter glasses until having moved the target disc by at least 20 mm). If this time limit was exceeded, the trial was repeated at a randomly determined later time. For each participant, trials were presented in a different, computer generated (pseudo) random order. Each participant performed 72 grasps (4 sizes of the target disc $\times$ 2 illusion conditions $\times$ 9 repetitions).

In the perceptual task, participants adjusted an 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 (pseudo) randomly to be in a range of ± 10 mm relative to the target disc (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, we 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 controls experiments). The adjustment method has the advantage of being more efficient. The LC shutter glasses suppressed vision as soon as the participant had finished the adjustments and until the next trial was set up by the experimenter. As in the grasping task, trials were presented in (pseudo) random order. Each participant performed 24 adjustments (4 sizes of the central disc $\times$ 2 illusion conditions $\times$ 3 repetitions). The tasks were performed in separate blocks, with the succession of the tasks being counterbalanced between participants. In both tasks, the LC shutter glasses were opaque while the experimenter prepared the trial. When finished, the experimenter pressed a button to open the LC shutter glasses and to start the trial.

Data analysis

For each grasp, time was normalized relative to movement onset ($t = 0\%$) and the time of the maximum grip aperture ($t = 100\%$). After normalization, the grip aperture was determined at the normalized times: 0%, 25%, 50%, 75%, 100% (cf.

Fig. 1c). These time points are the same as were used by Danckert *et al.* (2002). Time points *after* the maximum grip aperture were not included in the analysis, because here the fingers are already very close to the target and quite often one or the other finger already touches the target object which would contaminate the data (see also the Discussion section). To be maximally comparable to previous studies, the same criterion for movement onset was used as in the study of Glover and Dixon (2002): Movement onset was defined as the first time when the velocity of the thumb exceeded a value of 0.1 m/s. Maximum grip aperture was defined as the maximum of the aperture values between onset of the movement and reaching the disc.

For each participant and each time point, the mean illusion effect (i.e. mean grip aperture in the small context conditions minus mean grip aperture in the large context conditions, pooled across all sizes of the target disc) and the mean slope (relating physical size to grip aperture) were calculated. Then, for each participant and time point, the corrected illusion effect was calculated by dividing the mean illusion effect by the mean slope. It is important to perform the correction for each participant individually, using her/his individual illusion effect *and individual slope*. If the correction were done using the individual illusion effect, but the *average* slope (averaged across all participants) this would result in a wrong estimate, because the variability of the slopes between participants would not be taken into account. Usually (but not always) this latter method will result in an *underestimation* of the variability for the corrected illusion effects (and, consequently, in liberal statistical tests). Unfortunately, this problem is present in the study of Glover and Dixon (2002). For comparison, we calculated the corrected illusion effects in the same way as Glover and Dixon (2002) did. This results in corrected illusion effects of: 1.32 ± 0.34 for $t = 100\%$, 1.23 ± 0.34 for $t = 75\%$, 1.27 ± 0.37 for $t = 50\%$, 1.14 ± 0.78 for $t = 25\%$, and 21.51 ± 11.44 for $t = 0\%$. Comparing these values to the values in the column 'Corrected effect' of Table 2 shows that usually the variability is underestimated by this method.

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 described as $X \pm Y$, X denotes the mean and Y the standard error of the mean.

RESULTS

The Results section is divided into two parts: The first part describes details of the variables which were the basis for the time normalization. The second part describes the illusion effects in normalized time.

Variables on which time normalization is based

The normalization is based on movement onset time and on the time from movement onset until maximum grip aperture. The average movement onset time was

782 ± 60 ms, the average time to maximum grip aperture was 679 ± 32 ms. To test whether the normalization depended in some way on the experimental conditions, repeated measure ANOVAs were calculated for these times. None of the factors size of target disc (28, 31, 34, 37 mm), illusion context (small *vs*. large context circles), or interaction between these two factors affected movement onset time or time to maximum grip aperture (all $p > 0.27$). We also tested whether a difference in grasp speed between participants affected in some way the size of the illusion effect. A correlation analysis indicates that this was not these case (correlation between movement onset time and illusion effect on MGA: $\rho = 0.30$, $t(24) = 1.5$, $p = 0.14$; correlation between time to maximum grip aperture and illusion effect on MGA: $\rho = 0.35$, $t(24) = 1.8$ $p = 0.08$).

Results of time normalization

Figure 2 shows grip aperture as a function of size of the target disc, illusion context, and normalized time. Inspection of the figure shows that: (a) The slopes of the linear functions which relate grip aperture to physical size are smaller at earlier time points. (b) The effect of the illusion is also smaller at earlier time points. Both results are reflected in ANOVAs which were calculated separately for each time point (Table 1) and can also be seen in the column 'Illusion effect' of Table 2 which shows the mean illusion effect (pooled across disc sizes) for each time point.

It is not surprising that at earlier time points the effects of physical size and of the illusion on grip aperture are smaller. This is due to the fact that at the beginning of each trial the fingers are resting and in consequence the effects on grasping have to build up over time. In order to assess whether the illusion effects are larger at early than at late time points, we have to *correct* the measured illusion effects for the slope with which grip aperture depends on physical size. This correction was suggested by Glover and Dixon (2001a) and also, in a slightly different context, by Franz *et al*. (2001). For details of the correction, see the Method section.

The last columns of Table 2 contain the corrected illusion effects for each time point. The table shows that the corrected illusion effects are constant over time. Only at movement onset ($t = 0\%$), does the corrected illusion effect seem to be increased. However, the huge standard error indicates that this is not a statistically reliable effect. Note that the large variability of the corrected effect at early time points is an artefact of the correction: We divide the illusion effect by the slope, and the slope gets closer and closer to zero for earlier times. Because the slope is the denominator, even small variations of the slope result in huge variations of the corrected effect (see also Glover and Dixon, 2002 for a discussion of this problem).

For comparison with the perceptual effect of the Ebbinghaus illusion, the same correction as in grasping was performed on the adjusted sizes obtained in the perceptual task. The perceptual illusion effect was 1.45 ± 0.12 mm and the corrected illusion effect was 1.32 ± 0.11 mm. Comparing these values to Table 2 shows that the effects of the Ebbinghaus illusion did not differ between perception

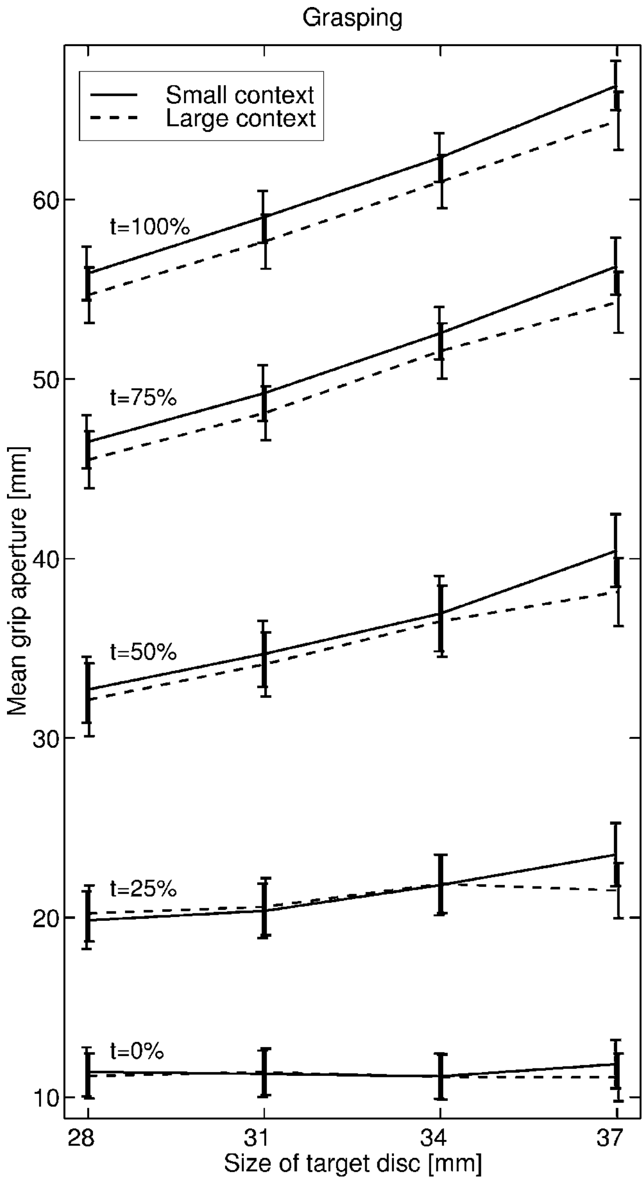

Figure 2. Grip aperture at different time points of the grasp movement: The mean grip aperture is shown as a function of the size of the target disc, of the illusion context, and of time. Time is normalized such that $t = 0\%$ corresponds to the start of the movement and $t = 100\%$ corresponds to the time of the maximum grip aperture. At $t = 214\%$, the participants had already lifted the target disc. Error bars depict ± 1 standard error of the mean. Note that these error bars contain within-subjects as well as between-subjects variability. Therefore, they do not well reflect the highly significant (within-subjects) illusion effects found in the ANOVAs. The error bars in Franz *et al.* (2000) for $t = 100\%$ reflect the significant illusion effects better because they were corrected such that they only contain the within-subjects variance. For statistical reasons, this correction is not possible if all time points are compared (cf. Loftus and Masson, 1994).

Table 1.
ANOVAs for grip aperture at the different time points

Time	GD-Time	Main effect size of target disc		Main effect illusion		Interaction size × illusion	
		F	*p*	*F*	*p*	*F*	*p*
100%	app. 65%	174.8	<0.001***	15.2	0.001***	0.6	0.649
75%	app. 49%	155.7	<0.001***	13.1	0.001**	1.0	0.417
50%	app. 33%	62.3	<0.001***	11.8	0.002**	2.1	0.107
25%	app. 16%	12.8	<0.001***	2.2	0.155	3.8	0.014*
0%	0%	1.8	0.155	3.5	0.072	3.1	0.031*

Note. For each normalized time point an individual repeated measures ANOVA was calculated on the grip aperture. Factors were size of target disc (28, 31, 34, 37 mm) and illusion context (small vs. large context circles). For a graphic depiction of the corresponding mean values see Fig. 2. Time is normalized such that 0% corresponds to movement onset and 100% to the time of the maximum grip aperture. Glover and Dixon (2002) used a different end-point for the time normalization. The column GD-Time provides a translation to their time normalization.

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 2.
Illusion effects and corrected illusion effects

Time	GD-Time	Illusion effect		Corrected effect	
		M	(SE)	M	(SE)
100%	app. 65%	1.47	(0.38)	1.45	(0.39)
75%	app. 49%	1.28	(0.35)	1.48	(0.40)
50%	app. 33%	0.97	(0.28)	1.40	(0.41)
25%	app. 16%	0.33	(0.23)	1.59	(3.73)
0%	0%	0.23	(0.12)	21.52	(30.83)

Note. Illusion effects are pooled across the different sizes of the target disc. Illusion effects are calculated by subtracting the mean grip apertures in the large context conditions from the mean grip apertures in the small context condition. The corrected illusion effects are calculated by dividing the illusion effects by the slope which relates grip aperture to physical size of the target disc. See method section for details. Time is normalized such that 0% correspond to movement onset and 100% to the time of the maximum grip aperture. Glover and Dixon (2002) used a different end-point for the time normalization. The column GD-Time provides a translation to their time normalization. M is the mean, SE is the standard error of the mean.

and grasping, as was already discussed by Franz *et al.* (2000; but see also Haffenden *et al.*, 2001, and Franz *et al.*, 2002)

DISCUSSION

The Ebbinghaus illusion clearly affected grasping, not only at the time of the maximum grip aperture, but also as early as 50% of the time between movement onset and maximum grip aperture. Also, the corrected illusion effects (which are corrected for the different slopes between grip aperture and physical size) are remarkably constant over time. Most importantly, the corrected illusion effects are not increased at early time points (as was suggested by Glover and Dixon, 2002).

How can these findings be related to earlier studies? Danckert *et al.* (2002) performed a similar study on the Ebbinghaus illusion and found a decrease of the illusion effects at early time points. However, these results do not contradict our results because Danckert *et al.* (2002) did not correct for the decreased slopes between grip aperture and physical size at earlier time points. (To be more specific: Danckert *et al.*, 2002, did correct for the different slopes between grasping and the perceptual measure at $t = 100\%$ of their time. But they did not correct for the different slopes which are present in grasping across the different time points.) Without this correction we also find a decrease of the illusion effect at earlier time points (cf. Table 2, column 'Illusion effect'). Note that the correction is an integral part of Glover and Dixon's (2001a, 2002) argument and therefore it seems difficult to test their planning/control model based on the raw illusion effects alone.

Glover and Dixon (2002) found a larger corrected illusion effect of the Ebbinghaus illusion for early time points than for late time points. This conforms with their planning/control model and seems to contradict our data. However, a closer inspection of their results shows that this decrease of the illusion effect over time is partially based on very late time points, well beyond the time of the maximum grip aperture (which corresponds to 100% in our time and to 65% in Glover and Dixon's time). We, as well as Danckert *et al.* (2002), did not include these very late time points in our analyses because after the maximum grip aperture the fingers are already in close proximity to the target object and therefore can be affected by the physical size of the object.

This can happen in two different ways which both will diminish the measured illusion effect: (a) The object could be larger in reality than the motor system expects. In this case, one finger or both fingers will 'bump' into the object earlier than expected. In consequence, the finger will be slowed down and this will lead to a larger aperture between the two fingers than was programmed by the motor system. The aperture will be more veridical and this will artificially reduce the measured illusion effect. (Note that this problem is already present when only one finger touches the object!) (b) The object could be smaller in reality than the motor system expects. In this case, the fingers will touch the object later than expected and the fingers will close down more than was originally programmed by the motor system. Thus, during the time between expected contact and actual contact, the aperture will be decreased such that it will be more veridical. In consequence, the measured illusion effect will be artificially reduced. This analysis shows that in order to correctly measure the illusion effect, we not only have to make sure that none of the fingers had contact with the target object (case a), but also there has to be a small 'safety margin' of about the size of the illusion effect between the target object and the fingers (case b).

Most likely the fingers touched the object at $t = 100\%$ in Glover and Dixon's study, because this was defined as the time when the thumb ceased to move in the forward direction. To see this, try it yourself: Place an object in front of you, grasp it, and move it either toward yourself (as participants did in Glover and Dixon, 2002), or sideways (as participants did in the present study). Watch for the time when the thumb no longer moves in the forward direction. Usually, you will have touched the object at this time. Note that touching the target object *selectively* decreases the measured illusion effect but not the slope with which grip aperture depends on physical size. Therefore, the corrected illusion effects (as discussed above) are no solution to this problem. If, however, we decide to exclude these late time points (beyond 65% in Glover and Dixon's time) from the analysis, then the data of Glover and Dixon (2002) are less convincing and the difference between our data and theirs is much smaller. (Also note that it seems likely that Glover and Dixon underestimated the variability of the corrected illusion effects; see the Method section for details.)

While the late time points pose serious methodological problems, it is not necessary to include these time points for a test of Glover and Dixon's planning/control model. Glover and Dixon assume that maximum grip aperture is already under strong online control and therefore that at least some reduction of the illusion effects should already have happened (cf. Glover and Dixon, 2002). In fact, Glover and Dixon argued that the marginal illusion effects which some studies (e.g. Aglioti *et al.*, 1995; Haffenden *et al.*, 2001) found for maximum grip aperture are due mainly to these corrective effects of online control. As mentioned above, our data do not support this prediction: The illusion effect was constant for even earlier time points than those analysed by Glover and Dixon (the earliest time point they analysed was 62% in our time and 40% in their time).

But how general is this result? Maybe the decay of the illusion effect caused by online control can be measured only if there is visual feedback during the grasp, while in our study the grasps were performed without visual feedback. However, the planning/control model predicts a decay of the illusion effect even if there is no visual feedback. This decay should be due to corrections based on proprioception, efference copy, and a stored visual image. Nevertheless, the planning/control model predicts a stronger decay if there is visual feedback available (Glover and Dixon, 2002, p. 271). Interestingly, and contrary to this prediction, Glover and Dixon (2002) found in their no-vision condition a (numerically) larger decay than in their vision conditions (cf. Glover and Dixon, 2002, p. 272 and Fig. 7). In consequence, there is good reason to use this condition as a test for the planning/control model. Note also that Glover and Dixon's result (largest decay in no-vision condition) is hard to explain with the planning/control model. However, it could easily be explained if one assumed that in the no-vision condition the grasps are less precise such that the fingers are more likely to have had contact with the target object at $t = 100\%$ in Glover and Dixon's time.

CONCLUSIONS

Glover and Dixon (2002) found that the effects of the Ebbinghaus illusion on grasping are largest at early phases of the grasp movement and then decrease over time. They interpret this as evidence for two different representations of target size which successively affect the motor system. A reanalysis of a large data set (Franz *et al.*, 2000) does not support this view. Instead, in our data the effects of the Ebbinghaus illusion on grasping are remarkably constant over time.

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