Representational momentum in perception and grasping: Translating versus transforming objects

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Representational momentum is the tendency to misremember the stopping point of a moving object as further forward in the direction of movement. Results of several studies suggest that this effect is typical for changes in position (e.g., translation) and not for changes in object shape (transformation). Additionally, the effect seems to be stronger in motor tasks than in perceptual tasks. Here, participants judged the final distance between two spheres after this distance had been increasing or decreasing. The spheres were two separately translating objects or were connected to form a single transforming object (a dumbbell). Participants also performed a motor task in which they grasped virtual versions of the final objects. We found representational momentum for the visual judgment task for both stimulus types. As predicted, it was stronger for the spheres than for the dumbbells. In contrast, for grasping, only the dumbbells produced representational momentum (larger maximum grip aperture when the dumbbells had been growing compared to when they had been shrinking). Because type of stimulus change had these different effects on representational momentum for perception and action, we conclude that different sources of information are used in the two tasks or that they are governed by different mechanisms.

Keywords: representational momentum, visuomotor, human, grasping, boundary extension

Introduction

When observers are asked to indicate the stopping point of a moving object, they typically indicate some point further forward in the direction of the (actual or implied) motion. This phenomenon is called representational momentum (Freyd & Finke, 1984; for a review, see Hubbard, 1995, 2003; for a recent collection of related work, see Thornton & Hubbard, 2002). In the first study that showed representational momentum (Freyd & Finke, 1984), observers were presented with three discrete visual presentations of a rectangle rotating in the picture plane. The observers were asked to remember the position of the third item and to indicate whether a fourth rectangle was the same as the third or not. Freyd and Finke found that the fourth rectangle was more likely to be erroneously judged as being the same when it was rotated forward in the direction of motion from the true stopping point, versus the same distance backwards. Since this initial study, many other examples of forward displacement have been found, using a variety of stimuli, including single translating objects (Hubbard & Bharucha, 1988), groups of translating objects (Finke & Shyi, 1988), depth rotated novel figures (Munger, Solberg, Horrocks, & Preston, 1999), articulating human figures (Verfaillie & Daems, 2002), and crowds of human figures (Thornton & Hayes, 2004). In addition to implied motion sequences, representational momentum has been found with displays involving induced motion (Faust, 1990), smooth continuous motion (Hubbard & Bharucha, 1988; see also Kerzel, 2000), and in static scenes where motion is only suggested pictorially (Freyd, 1983; Kourtzi & Kanwisher, 2000).

The ability to find forward displacements across a wide range of display types led Freyd (1987) to predict representational momentum "for any dimension of continuous change." However, almost all of the evidence to date has involved either actual or implied motion, that is, a change of position over time. Brehaut and Tipper (1996) carried out several experiments to see whether they could demonstrate representational momentum with a completely different form of change. They presented participants with objects that changed brightness over time. Instead of representational momentum, they found exactly the opposite pattern: When the stimulus changed from dark to light, participants remembered the last instance of the stimulus as darker then it actually was and when the stimulus changed from light to dark, they remembered the last stimulus as being lighter than it was. This finding led Brehaut and Tipper to conclude that representational momentum might be something typical for *moving*, but not necessarily *changing*, stimuli.

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Several recent studies from our lab appear to be consistent with this notion. Visual tasks involving growing cubes (Franz, Bülthoff, Fahle, & Thornton, 2001), expressive faces (Thornton, 1997), deforming objects (Thornton, Vuong, Knappmeyer, & Bülthoff, 2002), and opening or closing pliers (Brouwer, Franz, & Thornton, 2003a; Brouwer, Thornton, & Franz, 2003b) all failed to provide clear evidence of representational momentum; most of them showed the opposite pattern. Although these stimuli involved motion of parts of the object, the overall stimulus did not change position and may be better described as changing identity or transforming rather than as moving. Previous findings by Kelly and Freyd (1987) also suggest that representational momentum might be typical for moving rather than for changing stimuli. Specifically, while they found representational momentum for coherent changes, such as shrinking (receding) and growing (approaching) squares, they did not find (strong) representational momentum for less coherent changes in shape.

The purpose of the present study was to create a display in which the effects of change in position (translation) and change in identity (transformation) could be directly compared. To do this we created two types of stimuli that varied in the degree of transformation while leaving most other aspects (including the degree of translation) constant. One type of stimulus consisted of two spheres that moved toward or away from each other; the other consisted of the same two spheres but the spheres were connected by a bar to form one single, transforming object ("dumbbells," see Figure 1). We used a standard probe task to measure visual representational momentum. For the spheres, being two separately translating objects, we predict stronger representational momentum than for the dumbbells, which can be seen as a single transforming object.

Previous studies have also suggested that the mode of response can make a difference in judging the final instance of an object. For example, Kerzel (2003) found stronger representational momentum when participants indicated the last position of a translating disk by pointing or by moving a cursor than when they judged the disc's position purely visually. In our previous work, when observers were asked to reach out and grasp the final instance of a transforming object, they opened their hands wider for growing or opening objects than for shrinking or closing objects (Brouwer et al., 2003a, 2003b; Franz, Bülthoff, Fahle, & Thornton, 2001). This behavior contrasted with visual tasks on the same displays, suggesting a possible difference between perception and action in this context. In the present work, we also asked participants to grasp the final instance of the spheres or dumbbells to further explore the differential effect of response mode on representational momentum.

Methods

The stimulus consisted of a sequence of 2D rendered images of dumbbells (Figure 1A) or spheres (Figure 1B), presented on a black background. The dumbbells and spheres were presented in two separate experiments, to different groups of participants. In the following, the methods will be described for the dumbbells. For the spheres, the experiment was exactly the same except for leaving out the bar that visually connected the two spheres in the dumbbell stimuli.

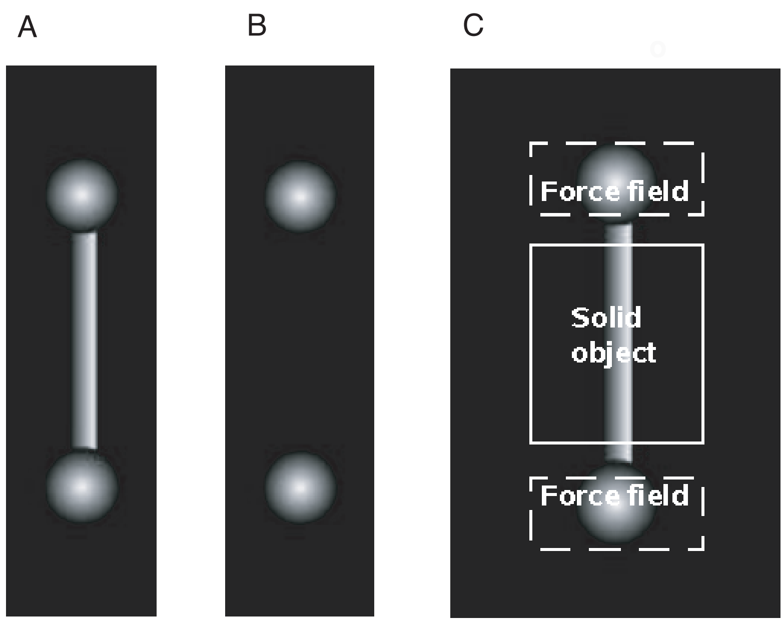

Figure 1. Stimuli. A. Dumbbells. B. Spheres. C. The white outlines indicate the size and position of the simulated haptic objects (invisible in the actual stimulus), which were exactly the same for the dumbbells and the spheres.

General setup and stimuli

Figure 2 shows a schematic overview of the experimental setup, which involved stereo-computer graphics (OpenGL, SGI Octane II, and Crystal Eye shutter glasses), two robot arms (Phantom^{TM}), a monitor, and a mirror. Participants were seated on a chair and looked down into the mirror through the shutter glasses. The monitor that was mounted above the mirror presented the stimuli so that they appeared to be on the left of a horizontal plane, at a distance of approximately 50 cm from the participants' eyes.

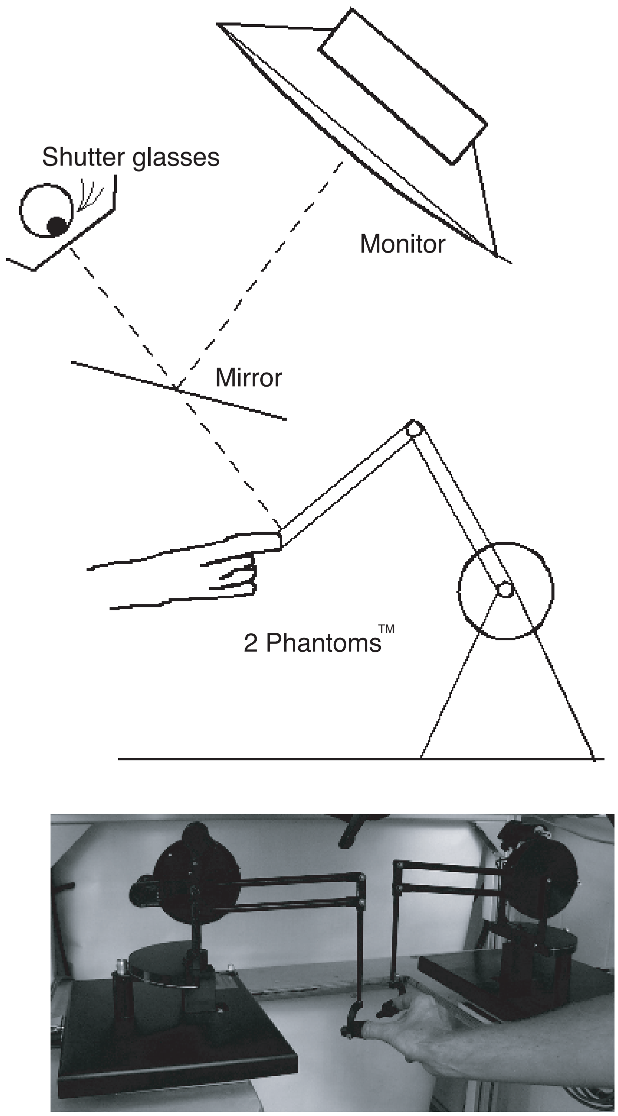

Figure 2. Overview of the experimental setup. The Phantoms were only used in the grasping task.

There were three kinds of (implied) motion of the dumbbells; increase, decrease, and static. In the conditions "increase" and "decrease," we presented participants three dumbbells in succession. The sequence could either imply an increasing distance between the spheres or a decreasing distance, in steps of 1 cm. Each dumbbell was presented for 250 ms, and there was a 250-ms interval in between. In the condition "static," only one pair of dumbbells was shown for 250 ms. We included this condition as a baseline and to check for a general decrease in remembered size, which appeared to be present in previous studies (Brouwer et al., 2003a, 2003b; Hayes & Freyd, 2002; Hubbard, 1996; Franz et al., 2001). The final distance between the outer edges of the spheres could be either 37 mm or 47 mm ("target size"). The stimuli were presented blocked for motion type (increase, decrease, or static). Previous studies have shown that forward displacement can be more reliably measured under these conditions, probably due to the increased predictability of the observed sequence (Kerzel, 2002). The order of the blocks was randomized.

Perceptual task

We used the traditional representational momentum probe task to measure perceptual performance. After the target pair of dumbbells had disappeared, and a 250-ms interval was presented, an additional pair of dumbbells was shown for 250 ms. This pair of "comparison" dumbbells could be either exactly the same as the target, or 2.5-, 5-, 7.5-, or 10-mm shorter or longer. The participants were asked to watch the whole sequence and to indicate whether the comparison dumbbell was different from the target by pressing the appropriate button on the keyboard that they held on their lap. They were told that the proportion of "different" and "equal" responses needed not be the same (in fact, the true proportion of "equal" comparison dumbbells was 0.11), and that the difference could be very small. The comparison dumbbells remained visible until the participants responded or until they had been presented for 3 s. In the latter case, participants received a message that they had been too slow and the trial was repeated later.

Participants practiced 10 trials at the start of each block (increase, decrease, and static). After that, they performed (2 target sizes × 9 comparisons × 8 repetitions =) 144 experimental trials. This results in a total of (144 × 3 motion types =) 432 perceptual trials for each participant. No feedback was given.

Grasping

During the grasping task, the thumb and the index finger of the participant's right hand were attached to two robot arms (Phantom ^{TM}). The positions of the tip of the thumb and the tip of the index finger in space were indicated by two stereoscopically presented digit markers (in the form of two small spheres). To start a trial, the participants had to bring these digit markers within a starting area that was specified by a large sphere. The starting area was about 20 cm to the right of the dumbbells. If the digits were in the correct position, the large sphere disappeared. The participants' task was to press the spheres of the target dumbbells together. Figure 1C indicates the relative size and position of three (invisible) haptic objects. The objects were all

2.5-cm high. If participants touched these, or the surface on which the dumbbells were lying, the phantoms provided resistance to make the dumbbells and the surface appear physically present. To press the spheres together, participants had to move their digits through "force field" objects (exerting a constant outward force of 0.8 *N*) until they collided with a simulated solid object that represented the maximally shortened version of the dumbbells. We created small gaps between the force fields and the simulated solid object, so that the participants did not experience a force pushing their fingers back after having succeeded. A successful grasp was indicated by the appearance of a pair of maximally shortened dumbbells.

Before starting with the experimental trials of each block (increasing, decreasing, and static), participants first practiced 10 trials in which the dumbbells remained visible all the time. After that they practiced for an additional 10 to 20 trials in which they were only allowed to start moving their hand after the dumbbells had disappeared, as in the actual experiment. If participants started moving away from the starting position before the dumbbells had disappeared, they received a warning that they started too early and the trial was repeated later. If the participants did not succeed within 3 s of the dumbbells' vanishing, they were warned that they were too slow and the trial was repeated later. For each block, there were (2 target size × 40 repetitions =) 80 experimental trials. This results in a total of (80 × 3 motion types =) 240 grasping trials for every participant.

Participants

Fourteen right-handed participants performed the tasks with the dumbbells. Fourteen new right-handed participants performed the tasks with the spheres. One participant of the latter group was excluded from analysis as he had profound difficulties with grasping in the virtual setup. In each group, seven participants did the perceptual task first and seven the grasping. They were paid for their participation.

Data analysis

Perceptual task

To estimate the remembered distance between the spheres in the perceptual task, we determined the "remembered size." This was the weighted mean for every participant for each of the six conditions (three motion types and two target sizes). To compute the weighted mean, we summed the products of the proportion "equal" responses and the distance between the spheres of the comparison dumbbells, and subsequently divided this by the total proportion of "equal" responses in that particular condition. We performed a repeated measures ANOVA on these remembered sizes with motion type and target size as within-subject factors and task order (whether the perceptual task was performed first or the grasping) as a between-subject factor. Representational momentum would be indicated by a larger remembered size for increasing than for decreasing distance between the spheres.

For each participant, we computed the representational momentum effect by subtracting the remembered size for the decreasing condition from the remembered size for the increasing condition.

Grasping

For each grasping trial, we calculated the maximum grip aperture (i.e., the maximum distance between thumb and index finger during the reach to grasp movement). Maximum grip aperture scales linearly with object size (Jeannerod, 1981, 1984). We used a repeated measures ANOVA with motion type and target size as within-subject factors and order as a between-subject factor to test for significant effects. Representational momentum would be indicated by a larger maximum grip aperture for dumbbells that had been increasing than for dumbbells that had been decreasing.

Similar to the perceptual task, we computed the representational momentum effect by subtracting the maximum grip aperture for the decreasing from that for the increasing condition for each participant.

We took 0.05 as the level of significance. All effects with a $p < .10$ will be mentioned. Mean values of the dependent variables will be presented as ± *SEM*.

Results

Perceptual task

Figure 3 plots the remembered size as a function of motion type and target size for the dumbbells (A) and the spheres (B).

Consistent with representational momentum, the remembered size was larger when the stimuli had been increasing than when they had been decreasing for both the dumbbells and the spheres. This is reflected by significant effects of motion type on the remembered size for both kind of stimuli (repeated measures ANOVAs, dumbbells: $F_{(2,24)} = 8.81$, spheres: $F_{(2,22)} = 18.37$, both $p < .01$). As predicted and depicted in Figure 3C, representational momentum was stronger for the spheres than the dumbbells (one-tailed, independent samples *t* test, $t_{(25)} = 1.82$, $p = .04$). Participants remembered the distance between the spheres on average as 2.43 ± 0.57 mm larger when they had been increasing than when they had been decreasing. This was 1.26 ± 0.32 mm for the dumbbells.

As indicated by Figure 3A and 3B, there was a clear effect of target size on the remembered size (repeated measures ANOVAs, dumbbells: $F_{(1,12)} = 2120.43$, spheres: $F_{(1,11)} = 9732.41$, both $p < .01$). For the dumbbells, participants remembered the target size of 47 mm on average as being 10.21 ± 0.23 mm larger than the target size of 37 mm. This corresponds to a slope of 1.021 ± 0.023 for

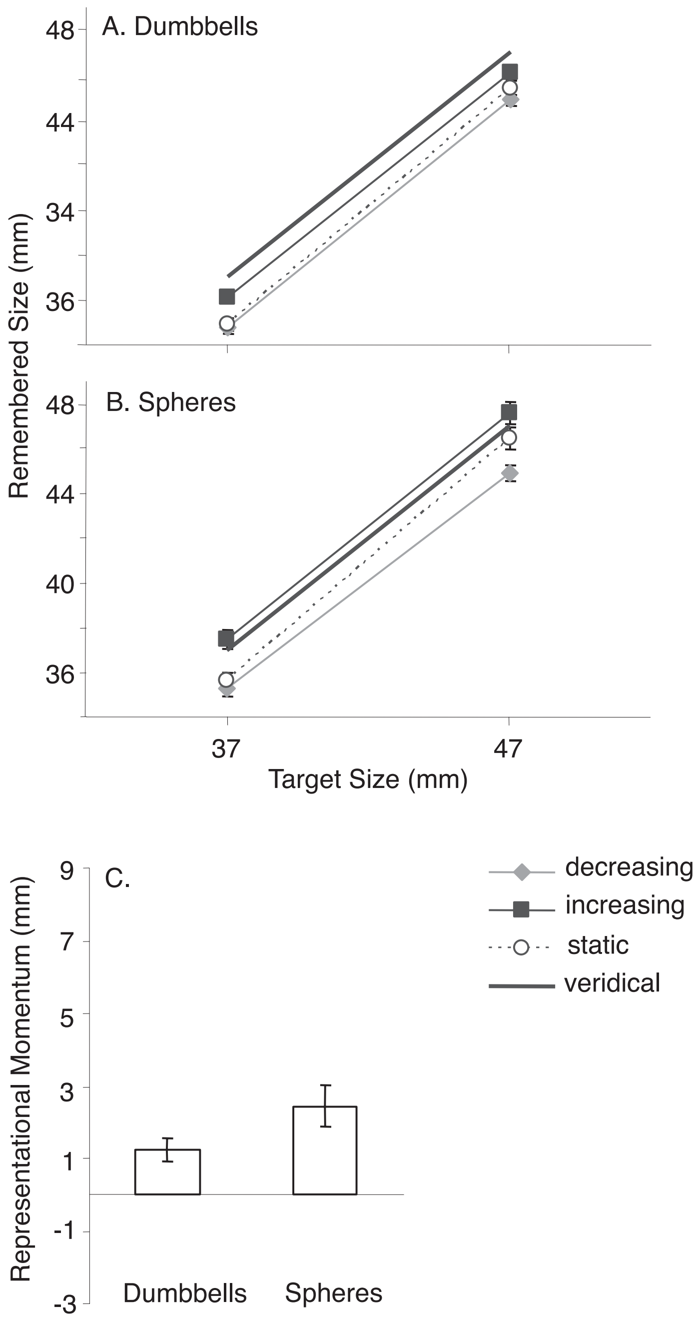

Figure 3. Perceptual task - the remembered sizes for each target size and motion type. Error bars represent the *SEM* (partly covered by the symbols). A. Results for the dumbbells. B. Results for the spheres. C. Representational momentum (remembered size for the increasing condition minus that for the decreasing condition) for dumbbells and spheres.

the linear fit, which relates remembered size to object size. For the spheres, the slope was 1.020 ± 0.010.

The repeated measures ANOVA that was performed on the remembered sizes of the dumbbells did not reveal any other significant effects. For the spheres, there was a significant interaction between motion type and size ($F_{(2,22)}$ = 10.71, p < .01). The nature of the interaction can be seen in Figure 3B; the slope is somewhat steeper for the static condition than for the decreasing and increasing conditions. Another significant interaction for the spheres was between motion type and order ($F_{(2,22)}$ = 5.65, p = .01). There seemed to be a stronger representational momentum effect for participants who did the grasping task first than for participants who did the perceptual task first. In our previous work using pliers (Brouwer et al., 2003a, 2003b), there was also an interaction effect between motion type and order on the remembered size, but this went in exactly the opposite direction; participants who did the perceptual task first showed representational momentum, whereas the others did not.

Most data points in Figure 3A and 3B are below the line that indicates veridical performance. This means that participants tended to remember the stimuli as smaller than they actually were, which is consistent with previous findings (Brouwer et al., 2003a, 2003b; Hayes & Freyd, 2002; Hubbard, 1996; Franz et al., 2001). On average, dumbbells were remembered as 1.64 ± 0.16 mm too small. For the spheres, this was 0.79 ± 0.29 mm. One-tailed one sample t tests indicated that both biases were significantly different from zero ($t_{(13)}$ = 10.37, p < .01 and $t_{(12)}$ = 2.69, p = .01, respectively). An independent samples t test indicated that the bias was significantly stronger for the dumbbells than for the spheres ($t_{(25)}$ = 2.60, p = .02).

On average, the remembered sizes of the static condition are in between those of the increase and decrease condition. Paired t tests indicated that the remembered size for the static condition was not different from the remembered size averaged across the decrease and increase condition (dumbbells: $t_{(13)}$ = 1.15, p = .27 and spheres: $t_{(12)}$ = 0.77, p = .46).

Grasping

For the dumbbells, the average maximum grip aperture was 95 ± 4.64 mm. The participants' averages ranged between 69 mm and 118 mm. For the spheres, this was 85 ± 4.65 mm with a range of 67 mm until 124 mm.

Figure 4 plots the maximum grip aperture as a function of motion type and target size for the dumbbells (A) and the spheres (B).

There was a significant effect of motion type on the maximum grip aperture for the dumbbells (repeated measures ANOVA, $F_{(2,24)}$ = 4.12, p = .03) but not for the spheres (repeated measures ANOVA, $F_{(2,22)}$ = 0.04, p = .96). As indicated in Figure 4C, participants opened their fingers on average 5.90 ± 2.32 mm wider when the dumbbells had been increasing than when it had been decreasing. This is consistent with representational momentum. For the spheres, the maximum grip aperture was 0.57 ± 1.64 mm smaller in the increasing than in the decreasing condition, a trend that goes in the opposite direction of representational momentum. The difference between these effects was significant (independent samples t test, $t_{(25)}$ = 2.23, p = .04).

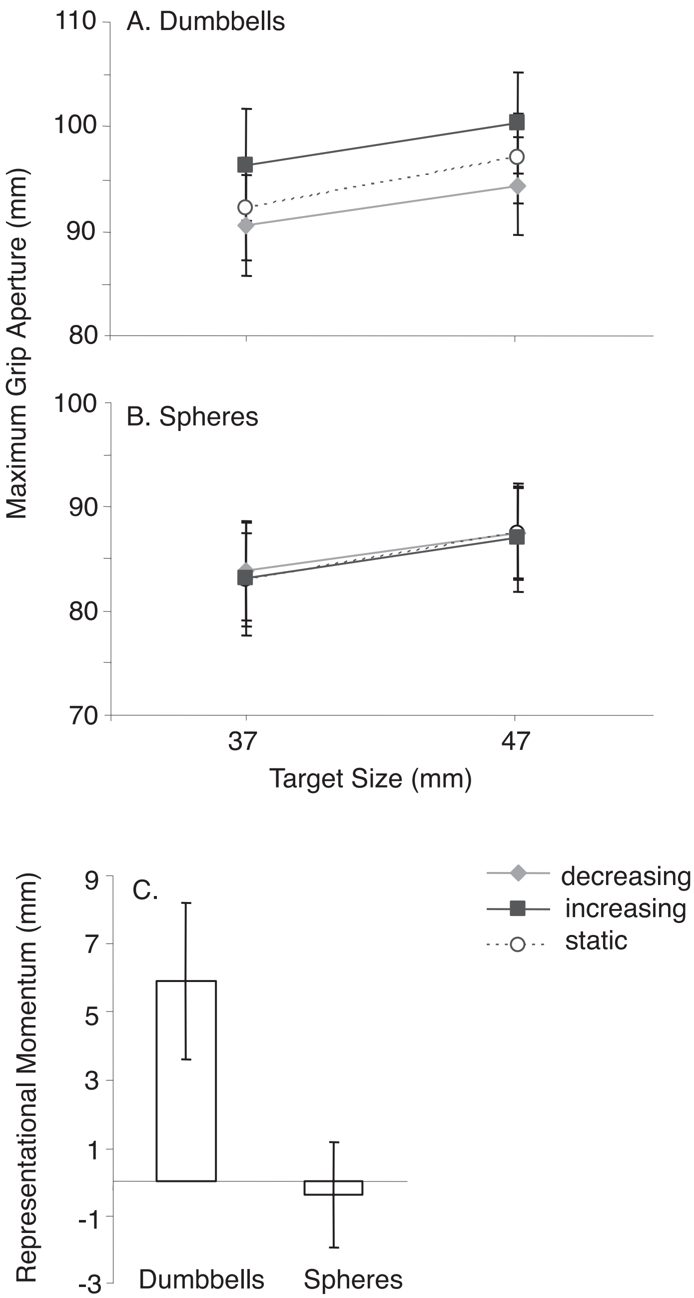

Figure 4. Grasping - the maximum grip aperture for each target size and motion type. Error bars represent the *SEM*. A. Results for the dumbbells. B. Results for the spheres. C. Representational momentum (maximum grip aperture for the increasing condition minus that for the decreasing condition) for dumbbells and spheres.

For both stimulus types, there was a significant effect of size (repeated measures ANOVAs, dumbbells: $F_{(1,12)}$= 30.86, spheres: $F_{(1,11)}$ = 88.62, both p < .01). When grasping dumbbells of 47 mm, participants opened their fingers 4.18 ± 0.76 mm wider than when the target size was 37 mm. This corresponds to a slope of 0.418 ± 0.076 for the linear fit, which relates maximum grip aperture to object size. The slope was 0.402 ± 0.042 mm for the spheres. In other grasping studies, in which physical objects are grasped, these slopes are usually larger (on average 0.82; Smeets & Brenner 1999). Our small slope may be due to participants' uncertainty about the object's size and distance because there is less information available about these properties in grasping with phantoms in a virtual environment, compared to grasping physical objects in a natural environment. In our previous work using cubes (Franz et al., 2001) and pliers (Brouwer et al., 2003a, 2003b), in which participants also grasped virtual objects by using the phantoms, the effect of target size was small as well (slopes of 0.38 and 0.32, respectively). The difference in slope, together with the finding that some subjects find it difficult to use the phantoms (see "Participants"), indicates that one should be careful to generalize grasping using phantoms to real grasping. Grasping with phantoms may be more like grasping impoverished stimuli using tools. However, our present aim is to measure representational momentum with a task that is more motorlike than visually judging, rather than investigate real grasping.

The repeated measures ANOVAs on maximum grip aperture did not reveal any other significant effects.

Figure 4A and 4B show that the average maximum grip apertures of the static conditions are in between those of the increase and decrease conditions. Paired t tests indicated that the maximum grip aperture for the static condition was not different from the maximum grip aperture averaged across the decrease and increase condition (dumbbells: $t_{(13)}$ = 0.53, p = .60 and spheres: $t_{(12)}$ = 0.07, p = .95).

Relation between perception and action

Figure 5 plots, for each participant, perceptual representational momentum against representational momentum in grasping for the dumbbells (A) and the spheres (B). A positive value means that the remembered width, or the maximum grip aperture, is larger in the increasing than in the decreasing condition (i.e., representational momentum). Clearly, there is no (positive) correlation in either of the graphs (dumbbells: R^2 < 0.01, p > .99; spheres: R^2 = 0.08, p = .35).

Discussion

The main findings of the present study are that representational momentum is influenced first by the type of stimulus change, and second, by the mode of response (perceptual or motor). Furthermore, the way in which the type of stimulus change affects representational momentum depends on whether the task was perceptual or motor in nature. More specifically, representational momentum was stronger for separately translating spheres than for transforming dumbbells in a visual judgment task. In contrast, there was no representational momentum for the translating spheres, but there was representational momentum for the transforming dumbbells in a grasping task. A final in-

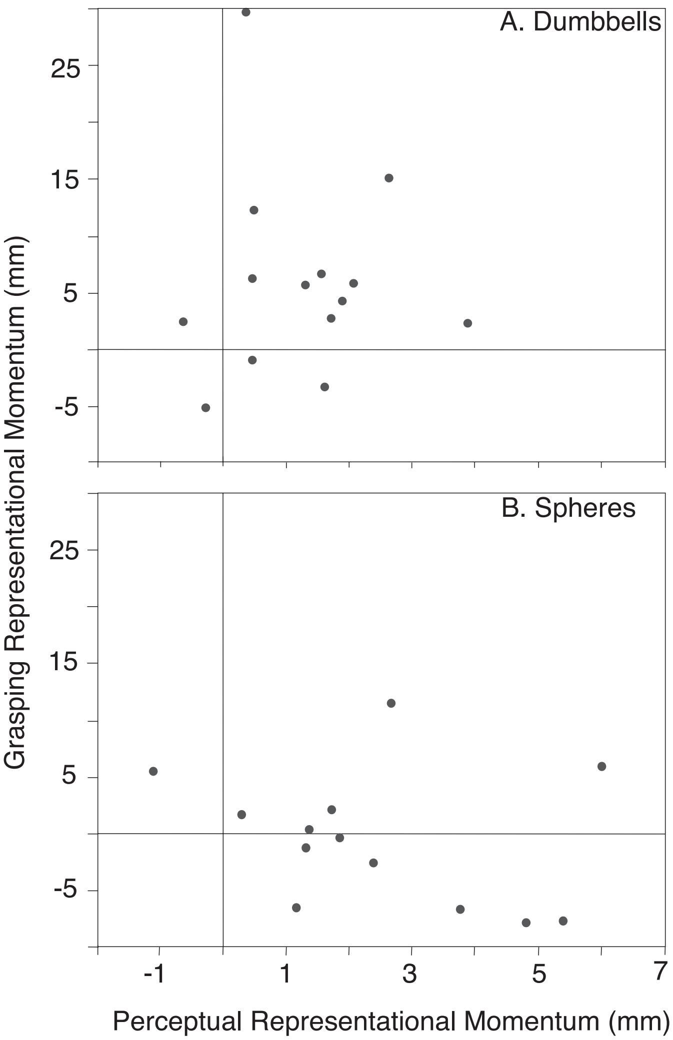

Figure 5. Representational momentum in grasping plotted against representational momentum in perception. A positive value means that the effect is in the direction of representational momentum. Every dot represents the data of one participant. A. Results for the dumbbells. B. Results for the spheres.

teresting result is that our stimuli were remembered as smaller than they actually were. We will discuss these results in more detail and speculate on explanations below.

In several previous studies, coherent stimulus changes failed to give rise to representational momentum in visual tasks. Typically, these studies involved manipulations that changed the identity of the stimulus, rather than the position. Here we compared memory for the final configuration of a changing display when that change either consisted of simple translation (spheres) or also involved object transformation (dumbbells). Consistent with the previous studies, we found that the simple addition of a connecting bar – altering a display with two translating spheres into a display with a single, transforming dumbbell – reduced representational momentum. Although weak, the dumbbells still gave rise to reliable forward shifts. This result is consistent with Kelly and Freyd (1987). One of their stimuli, a rectangular shape that grew or shrank along only one axis, also produced a weak but reliable representational momentum. Both their stimulus and our dumbbells did not only transform, but also contained a strong translation component. Other stimuli, in which there were no (clearly) translating components (e.g., the squares changing luminance of Brehaut & Tipper, 1996), showed an effect opposite to representational momentum.

The question arises as to why there would be a stronger representational momentum for translating than for transforming stimuli. Several authors suggest that the mechanism leading to the typically observed forward shifts or representational momentum might serve to anticipate the future position of an object (Brouwer, Middelburg, Brenner, & Smeets, 2003; Hubbard, 1998; Kelly & Freyd, 1987; Nagai, Kazai, & Yagi, 2002). Thus, representational momentum might be particularly salient when dealing with objects that change position over time.

Another mechanism may try to guard against anticipation in situations where it would not be appropriate, such as when changes have the potential to influence the identity of an object. This could lead to backward shifts in situations involving changes to object identity rather than object position (e.g., Brehaut & Tipper, 1996). These two mechanisms could be competing in cases where both transforming and translating components are present (cf., competing mechanisms proposed by Freyd & Johnson, 1987).

There was clear evidence for representational momentum with grasping the dumbbell stimuli, as we had expected from previous studies that showed strong representational momentum in motor tasks (Franz et al., 2001; Brouwer et al., 2003a, 2003b; Kerzel, 2003). Participants opened their fingers wider when a pair of dumbbells had been growing than when it had been shrinking, although we asked the participants to grasp the final pair and provided the appropriate feedback. Also in line with these previous studies, representational momentum for the dumbbells appeared to be stronger for the motor task than the perceptual task. In grasping, the amount of extra grip aperture for grasping increasing dumbbells relative to static dumbbells (half of the direction effect, about 3 mm), approaches the amount of extra grip aperture caused by a 1-cm increase in size (the size effect, about 4 mm). The step size of the inducing growing dumbbells was 1 cm. Thus, the size of the effect suggests that participants were aiming to grasp a pair of dumbbells that was almost one step further in the direction of the change. For visual judgment tasks, representational momentum is usually much smaller than the step size of the inducing stimuli.

In contrast to the large effect of the direction of change in grasping dumbbells, there was no effect of direction at all for grasping the spheres. Note again that the spheres and the dumbbells were identical in all haptic and visual respects, except the spheres of the dumbbells were visually connected by a bar.

Because grasping and perception produced opposite effects of type of stimulus change on representational momentum, we clearly cannot generalize the hypothesized explanation for the difference between translating and transforming stimuli from the visual task to the motor task. The different effect of type of stimulus change on a motor and a visual task shows that anticipation in grasping and perception are not simply governed by the same mechanism or by the same visual information. This was already suggested by our previous study involving opening and closing pliers (Brouwer et al., 2003a, 2003b). In that study, there was very little evidence of visual representational momentum, but there was representational momentum in grasping. Furthermore, there was no between-subject correlation between representational momentum measured with the perceptual and the grasping task. However, the dissociation found in that study could have been special for cases in which there was no visual representational momentum. In the present study, visual representational momentum occurred for both the perceptual and the grasping task, but a dissociation was still found.

The separate visual pathways hypothesis (Goodale & Milner, 1992) proposes that visual information is processed in two cortical streams. The ventral stream processes visual information that is used for perceptual identification of objects, whereas the dorsal stream processes information to serve visually guided action. According to this theory, a difference between perception and action is not unexpected. However, the theory further states that the dorsal pathway (i.e., action) is largely resistant to illusions, in contrast to the ventral pathway (perception). Studies that support the visual streams hypothesis show more accurate performance for grasping the center disc of the Ebbinghaus illusion (Aglioti, DeSouza, & Goodale, 1995; Haffenden & Goodale, 1998) than for visually judging its size, which clearly reflects the illusion. The results for the spheres were in the direction expected by the visual streams hypothesis. In contrast, the pattern found by Kerzel (2003) and by us with the pliers and the dumbbells, was exactly the other way around: participants were more accurate in the visual than in the motor task. We prefer to explain different results for perception and action by a lack of properly matching the motor task to the visual task (Pavani et al., 1999; Franz et al., 2000; Franz, 2001; Franz et al., 2003) and a difference in the use of information for the different tasks (Smeets, Brenner, de Grave, & Cuijpers, 2002).

In our pliers study, we found a stronger forward shift for closing than for opening pliers. Similarly, Hayes and Freyd (2002), who used growing and shrinking squares (or approaching and receding squares), found a stronger forward shift for shrinking than for growing squares. To clarify whether there was a difference in strength of representational momentum between the different directions of motion, or whether there was a general tendency to remember things as too small that, together with effects of direction of motion, determined the final remembered size, we followed the example of Hubbard (1996) and included a static condition in this study. Consistent with Hubbard's results, we found that the average remembered size for the static condition was smaller than the actual target size, and that the remembered size of the static stimuli was in between that of the decreasing and increasing stimuli. Thus, the remembered size seems to be determined by the actual target size, representational momentum, and a general bias to remember the objects as a certain amount too small. This bias could be related to boundary extension (Intraub, 1997; Hubbard, 1996). Boundary extension is the tendency to remember a scene as if the limits of view have been extended outward, which would be, in the experiments mentioned, equivalent to remembering objects as smaller than they were. This tendency was stronger for the dumbbells than for the spheres. If participants attended more to the whole stimulus in the case of the dumbbells and to only one sphere when they were separate objects, this is not a surprising difference. Boundary extension that affects the whole dumbbell gives rise to dumbbells that are remembered as smaller than they were, but boundary extension that affects only one sphere gives rise to a sphere that is remembered as smaller than it was, but not to a (inward) change of position of the sphere.

In summary, we conclude that visual representational momentum is stronger for objects changing position than for transforming objects. Measuring representational momentum with a motor task gives the opposite result. This opposite effect of object change indicates that different information is used in judging stimuli for a visual task than for a motor task, or that different mechanisms process information for these two types of tasks. A clear goal for future studies will be to try to specify more precisely the nature of these differences. For example, examining eye movement patterns or assessing attentional deployment during grasping and perceptual judgments may help to shed light on the type of information being extracted. Similarly, such measures could also be used to investigate possible strategy differences adopted by observers when faced with the spheres or the dumbbells. Our use of blocked designs may have increased the tendency for observers to adopt specific strategies. Randomly presenting spheres or dumbbells may be a useful way to manipulate the use of strategies or more generally explore the impact of increased uncertainty (Kerzel, 2002).

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