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RESEARCH ARTICLE

Egocentric and allocentric localization during induced motion

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Abstract This research examined motor measures of the apparent egocentric location and perceptual measures of the apparent allocentric location of a target that was being seen to undergo induced motion (IM). In Experiments 1 and 3, subjects fixated a stationary dot (IM target) while a rectangular surround stimulus (inducing stimulus) oscillated horizontally. The inducing stimulus motion caused the IM target to appear to move in the opposite direction. In Experiment 1, two dots (flashed targets) were flashed above and below the IM target when the surround had reached its leftmost or rightmost displacement from the subject's midline. Subjects pointed open-loop at either the apparent egocentric location of the IM target or at the bottom of the two flashed targets. On separate trials, subjects made judgments of the Vernier alignment of the IM target with the flashed targets at the endpoints of the surround's oscillation. The pointing responses were displaced in the direction of the previously seen IM for the IM target and to a lesser degree for the bottom flashed target. However, the allocentric Vernier judgments demonstrated no perceptual displacement of the IM target relative to the flashed targets. Thus, IM results in a dissociation of egocentric location measures from allocentric location measures. In Experiment 2, pointing and Vernier measures were obtained with stationary horizontally displaced surrounds and there was no dissociation of egocentric location measures from allocentric location measures. These results indicate that the Roelofs effect did not produce the pattern of results in Experiment 1. In Experiment 3, pointing and Vernier measures were obtained when the surround was at the midpoint of an oscillation. In this case, egocentric pointing responses were displaced in the direction of surround motion (opposite IM) for the IM target and to a greater degree for the bottom flashed target. However, there was no apparent displacement of the IM target relative to the flashed targets in the allocentric Vernier judgments. Therefore, in Experiment 3 egocentric location measures were again dissociated from allocentric location measures. The results of this experiment also demonstrate that IM does not generate an allocentric displacement illusion analogous to the "flash-lag" effect.

Keywords Localization · Induced motion · Motion perception

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Introduction

Induced motion (IM) is the illusory perceived movement of a stationary visual stimulus (IM target) in the direction opposite the real motion of other stimuli (e.g., Duncker 1929). A familiar example is provided by the moon when viewed through moving clouds. Although the moon is essentially stationary from the perspective of the viewer, it appears to move in the direction opposite the cloud motion.

A second illusion that often accompanies IM is the experience that the IM target is displaced off in the direction of the IM. The presence of this spatial displacement effect depends to a large extent on the characteristics of the moving stimulus that induces the IM, referred to as the "inducer." As first noted by Bacon et al. (1982), the spatial displacement effect is obtained with inducers that shift relative to the median plane (i.e., "shifting inducers"), but not with those that remain centered on the median plane. Studies that have found the spatial displacement effect with shifting inducers include Abrams and Landgraf (1990), Bacon et al. (1982), Bridgeman et al. (1981), Bridgeman and Klassen (1983), and Post and Welch (2004). Studies that have found no spatial displacement effect with centered inducers include Bacon et al. (1982), Brenner and Smeets (1994) and Smeets and Brenner (1995). An exception is Abrams and Landgraf (1990, Experiment 3) who obtained the apparent displacement with a non-shifting inducing stimulus.

All of the studies cited above that found a spatial displacement effect used measures of the perceived egocentric location of the IM target, typically open-loop pointing at the target's apparent terminal position. An exception is Bridgeman and Klassen (1983), whose subjects pressed different keys corresponding to different perceived directions relative to the subject. Regardless of this distinction, in all cases the measure was of perceived egocentric direction.

From these studies it is well established that shifting inducers produce both IM and a perceived spatial displacement in egocentric coordinates of the IM target in the direction of its illusory motion. These studies have not, however, addressed the issue of whether IM is also accompanied by a perceived displacement of the IM target relative to other visual references that are not seen to undergo IM. That is, does IM produce a shift in perceived *allocentric* (as well as egocentric) coordinates? Post and Welch (2004) reported that the perceived displacement of the egocentric direction of an IM target by a shifting inducer was accompanied by a smaller displacement effect for other stimuli that were flashed briefly at the termination of the stimulus display. These findings might predict that the IM target will appear shifted relative to the flashed stimuli if an allocentric judgment such as Vernier alignment is examined.

The issue of whether IM is accompanied by an alteration in allocentric location perception is interesting in the context of a research literature demonstrating that visual motion is often associated with illusory allocentric displacement in the same direction as the apparent motion (see Whitney 2002, for a review). An extensively studied example is the "flash-lag effect", wherein a moving target is perceived to be displaced in the direction of motion relative to stationary stimuli that are flashed adjacent to it (e.g. MacKay 1958; Metzger 1932; Nijhawan 1994). Another example was provided by DeValois and DeValois (1991), who presented observers with three Gabor patches within stationary envelopes. Although the patches were physically aligned, motion of the Gabor in the center patch produced a perceived Vernier misalignment in the direction of apparent motion, which is referred to as "movement-related positional bias". Ramachandran and Anstis (1990) reported a similar effect in a study in which they showed that the apparent position of a physically stationary aperture appears displaced in the direction of an enclosed moving texture.

The purpose of the present research was to determine whether and to what extent conditions that produce IM and perceived egocentric displacement of the IM target also alter perceived allocentric location. In Experiment 1, subjects fixated a stationary dot stimulus inside a rectangular surround that oscillated horizontally. The dot and surround were extinguished when the surround was at its maximal displacement relative to the subject's median plane, a condition previously reported to produce the egocentric displacement effect for the IM target (Abrams and Landgraf 1990; Bacon et al. 1982; Bridgeman et al. 1981; Bridgeman and Klassen 1983; Post and Welch 2004). Open-loop pointing measures were obtained for the IM target's apparent terminal location to assess the presence and magnitude of an egocentric displacement effect. Other dots were flashed briefly above and below the IM target at the termination of the display and subjects judged the Vernier position of the IM target relative to these other dots to examine the possibility of an allocentric displacement effect.

Experiment 1

Method

Subjects

A four right-handed volunteers (two males and two females), aged 19–51 years (mean 28 years), served as subjects.[1] All subjects had normal vision and were able either to focus at the distance of the displays without correction or could do so with contact lenses. Two subjects were familiar with the experimental hypotheses. The research was approved by the ethics committee at the University of California at Davis and therefore accords with the 1964 Declaration of Helsinki. All subjects gave their informed consent prior to inclusion.

Apparatus

The apparatus is depicted schematically in Fig. 1. Subjects were seated and viewed the stimulus displays by looking

[1] One subject was 51 years old, while the other three were 19–21 years old.

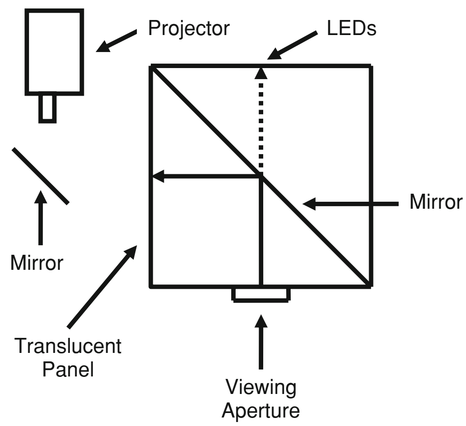

Fig. 1 Schematic diagram of apparatus

into a box containing a partially reflecting mirror that was rotated 45° about the vertical axis with respect to their line of sight. Subjects could reach under the mirror and touch the rear wall of the box at the apparent location of various display features with their right index finger. The stimulus display is depicted schematically in Fig. 2.

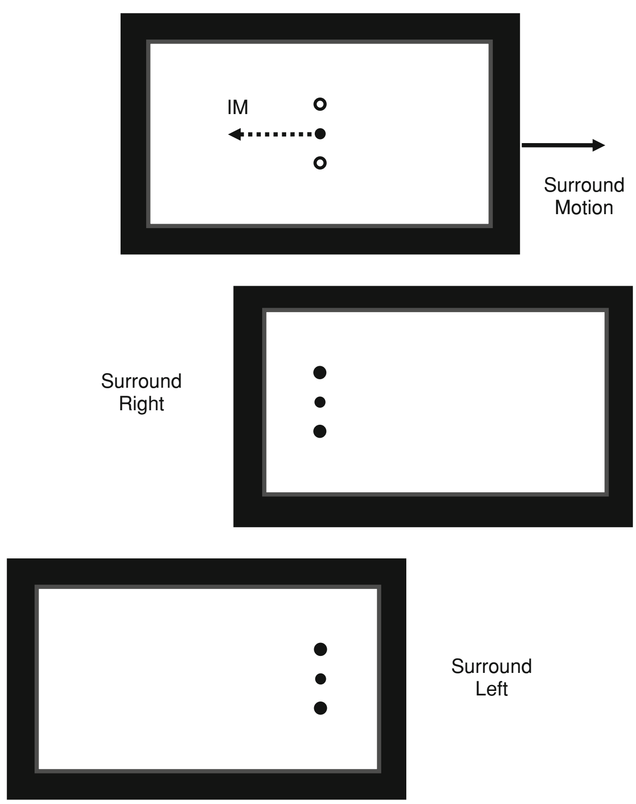

Fig. 2 Display used in Experiment 1. Central dot stimulus (IM target) appears to move opposite surround motion. Upper and lower dot stimuli (flashed targets) flash when surround is at maximal *left* or *right* displacement

The surround stimulus was a 9-cm vertical by 15-cm horizontal rectangle (outer dimensions) with 1-cm wide sides. It was rear-projected onto the translucent left wall of the box and, because of the mirror, appeared to subjects to be in front of them. The rectangle was projected by a slide projector and reflected from a mirror on a galvanometer that was controlled by a microcomputer with digital-to-analog circuitry and an amplifier. A shutter under microcomputer control regulated the presentation of the rectangle. A red LED that served as the IM target was mounted behind the translucent rear wall of the box at eye level and in the middle of the vertical extent of the rectangle. Two other LEDs, the "flashed targets", were mounted on the rear of the box 2.5 cm above and below the IM target. The horizontal displacement of the flashed targets relative to the IM target was adjustable by the experimenter and could be briefly illuminated under microcomputer control. A sensor from an Isotrak system was attached near the tip of the subject's index finger for the purposes of pointing measurement. The viewing distance to the rear wall of the box and of the optical path from the eyes to the displays were both 45 cm.

Procedure

Subjects participated in two experimental sessions, separated by at least a day. In one of these (Pointing session), open-loop pointing measures directed at the IM target and the bottom flashed target were obtained. In the other (Vernier session), judgments of the Vernier alignment of the IM target with the targets were obtained. The order of the sessions was counterbalanced across subjects.

Pointing session

At the beginning of each pointing session, the IM target was illuminated with the room lights on. Under these conditions, subjects were able to see both the LED and their finger while reaching toward it. Subjects placed their finger over the LED and the position of the finger was sampled. The horizontal coordinate of the finger was saved as a baseline measure to control for individual differences in sensor placement or bias in pointing toward visible targets.[2] In additional preliminary measures, subjects performed open-loop pointing for briefly flashed targets presented at locations ranging between 6 mm left of straight-ahead and 6 mm right. The stimulus locations were each 2 mm step within this range. Five measures were obtained for each subject at each target location. The regression of open-loop

[2] The range of individual differences on these pre-measures was about 1.0 cm, which is within the width of a fingertip.

pointing response versus target location was highly linear, with a slope of 1.07 and R-squared equal to 0.986.

Following the baseline measures, pointing accuracy was assessed under two conditions. In one condition (IM target trials), the IM target and surround stimulus were turned on and the subject fixated the IM target. After 2 s, the surround began oscillating while subjects maintained fixation on the IM target during 2.25 cycles of surround oscillation. Motion of the surround was sinusoidal at 0.3 Hz, with peak-to-peak amplitude of 5.2 cm (6.6°). This frequency and amplitude have previously been reported to produce robust IM in a similar display (Post et al. 1989), and each subject in the present experiment reported perceiving IM while viewing this display that was nearly equal to the extent of perceived frame motion. The surround started its motion centered around the IM target at peak velocity and terminated its motion at an eccentric location at zero velocity. During the last 100 ms of surround motion the flashed targets were flashed, immediately after which the IM target, flashed targets, and surround were extinguished. Subjects were instructed to reach immediately and touch the rear of the apparatus where they perceived the IM target to be when the flash occurred, and the fingertip position was sampled. Ten measures were obtained for trials on which the surround was moving rightward prior to offset and ten for trials on which it was moving leftward prior to offset. Following these measures, 20 trials were conducted on which subjects pointed at the apparent location of the bottom of the two flashed targets that had been flashed immediately prior to offset (flashed target trials).[3]

Vernier session

The Vernier session consisted of 24 trials in each of the three surround conditions (Surround Left, Surround Right, and Surround Center) during which subjects judged the alignment of the IM target with the flashed targets. On each trial in the Surround Left condition, the IM target and surround stimulus were turned on and the subject fixated the IM target centered in the surround. After 2 s the surround stimulus began oscillating. Surround motion was similar to that of the Pointing Session. The surround underwent 2.25 cycles of oscillation and then both the surround and the dot were extinguished. Motion of the surround was to the left during the final half-cycle and the surround was extinguished at the left-most extreme of its motion. The flashed targets were flashed during the last 100 ms of oscillation. Twenty-four trials occurred, eight with the flashed targets displaced 2 mm (0.25°) to the left of the IM target, eight with the flashed targets displaced 2 mm to the right of the IM target, and eight with all three targets vertically aligned. The order of these alignments was random. Following offset of the display, subjects reported whether the IM target appeared aligned with the flashed targets, or displaced to the left or right. The Surround Right condition was identical, except that motion of the surround was to the right during the final half-cycle and the surround was extinguished at the right-most extreme of its motion. In the Surround Center condition, the IM target and surround were turned on and subjects fixated the IM target. At the end of 9.4 s with the surround stationary the flashed targets were flashed and then the IM target, surround, and flashed targets were extinguished. The total duration of the IM target in each of the three surround conditions was 9.5 s.

Results

Pointing session

The horizontal coordinates of the baseline control pointing responses for the IM target that were obtained at the beginning of the session were subtracted from the horizontal coordinates of the pointing responses for the IM target and bottom flashed target on the experimental trials to yield an error score for each trial. These error scores were entered in a 2 (target: IM vs. Vernier) × 2 (surround displacement at offset: left vs. right) ANOVA. There was no statistically significant main effect for target [$F(1,39) = 1.51$, $P > 0.05$]. The main effect of surround displacement at offset was statistically significant, with pointing displaced an average of 1.08 cm to the right on surround offset left trials relative to the surround offset right trials [$F(1,39) = 76.54$, $P < 0.001$]. The interaction of target and surround offset was statistically significant, as well [$F(1,39) = 29.15$, $P < 0.001$]. This interaction is depicted in Fig. 3, which shows the mean pointing error for both targets and surround displacements at offset. It can be seen in the figure that the effect of surround offset direction was greater for the IM target than for the flashed target. Post hoc analyses of this interaction indicated that with the right surround offset, pointing at the IM target was significantly to the left of pointing at the flashed target [$F(1,39) = 23.71$, $P < 0.001$], while with the left surround offset pointing was significantly to the right of pointing at the flashed target [$F(1,39) = 7.03$, $P < 0.05$]. The results for each subject were consistent with the effects reported for the mean data.

Vernier session

Vernier judgments. The results obtained for the Vernier judgments are presented in Table 1. Vernier judgments were evaluated in terms of whether the IM target was

[3] The bottom flashed target was selected because pointing responses directed at the upper flashed target might have been subject to interference by the mirror reflecting the surround stimulus.

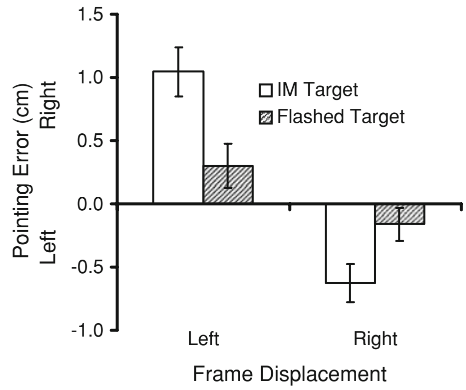

Fig. 3 Pointing errors in Experiment 1 for both IM and flashed targets and both directions of surround motion. *Error bars* correspond to ±1 SE

Table 1 Vernier judgments of Experiment 1: IM target was presented either aligned with two flashed targets or displaced 2 mm to the right or left for three conditions of surround location

Surround condition	IM target displacement	Perceived displacement		
		Left	Aligned	Right
Center	Left	32	0	0
	Aligned	0	32	0
	Right	0	2	30
Left	Left	31	1	0
	Aligned	2	29	1
	Right	0	5	27
Right	Left	30	2	0
	Aligned	0	31	1
	Right	0	1	31

Subjects reported the perceived location of the IM target relative to the flashed targets

reported in its correct relationship relative to the flashed targets, or was reported erroneously to be to the right or left of the physical relationship ("rightward" and "leftward" errors, respectively). For the Surround Center trials, judgments were accurate on 94 of 96 trials (98% accuracy). The errors consisted of two trials on which the IM target was presented to the right but was reported to be in the central position (leftward errors). When the surround was displaced to the left at stimulus offset, judgments were accurate on 87 of 96 trials (91% accuracy). Of the nine trials that were incorrect, the IM target was reported to the right of its objective location (rightward errors) on two trials, and to the left of its objective location (leftward errors) on seven trials. When the surround was displaced to the right at stimulus offset, judgments were accurate on 92 of 96 trials (96% accuracy). Of the four trials that were incorrect, the IM target was reported to the right of its objective location (rightward errors) on three trials and to the left of its objective location (leftward errors) on one trial. Summing across the two directions of surround offset, ten of the thirteen errors were in the same direction as surround offset and three were in the opposite direction. This pattern is different from that in the pointing data, where mean errors were in the opposite direction of surround offset. A chi-square analysis indicated that the effect of surround offset on error direction was not statistically significant [χ^2 (1) = 3.77, $P > 0.05$].

Discussion

Experiment 1, like several prior studies (Abrams and Landgraf 1990; Bridgeman et al. 1981; Bacon et al. 1982; Post and Welch 2004), demonstrated that a shifting inducer alters open-loop pointing responses directed at the apparent location of an IM target. Thus, the perceived egocentric location of the IM target was shifted in the direction of the previously experienced IM. A similar but smaller effect was obtained for the pointing directed at the flashed target, indicating that the IM and flashed targets were perceived as being in different egocentric horizontal locations. The finding that egocentric displacement is greater for the IM target than for other briefly flashed targets replicates Post and Welch (2004).

The results obtained with the Vernier task displayed no effect of IM on perceived allocentric location. Whether the IM target was aligned with the flashed targets or shifted relative to them, the correct alignment was reported on nearly every trial. Because the effect of IM on pointing was 1.34 cm greater for the IM target than for the flashed target, the Vernier results would have been significantly different if the egocentric results also applied to the allocentric Vernier measures. Therefore, the egocentric results cannot account for the allocentric data.

This pattern of results is striking in that the effect of IM on subjects' pointing responses was not present in the Vernier judgments. This pattern is consistent with the results of Brenner and Cornelissen (2000), who found that whereas eye movements influenced egocentric judgments of spatial location, they did not influence simultaneous judgments of relative spatial positions. In both instances, it is apparent that different information contributes to the absolute and relative location judgments. The present results could be considered a potential instance of "vision–action dissociation" (e.g. Milner and Goodale 1995). In most reports of vision–action dissociation there is a perceptual illusion that is not reflected commensurately in motor responses (e.g. Aglioti et al. 1995; Creem and Proffitt 1998; Gentilucci et al. 1996; Haffenden and Goodale 1998; Loomis et al. 1992; Wraga et al. 2000). In the present study, the opposite pattern was obtained. Specifically, the IM illusion affected the motor responses, but not perceived allocentric location.

This is somewhat similar to the results of Yamagishi et al. (2001), who found that drifting Gabors, under some conditions, influenced pointing to a greater degree than the amount of their illusory perceptual displacement. Regardless of the fact that the present results are opposite the pattern typically reported with vision-action dissociation, they strongly support the hypothesis that motor responses such as open-loop pointing can be dissociated from visual awareness.

Experiment 2

In Experiment 1, the display was extinguished when the surround was at either the left-most or right-most extreme of its horizontal motion. Therefore, the eccentricity of the surround when it terminated covaried with both the immediately preceding surround motion direction and IM. When a visual stimulus such as the surround is presented in a location displaced laterally from the straight-ahead, its apparent location is displaced in the direction opposite the stimulus displacement (e. g., Bridgeman et al. 1997; Bruell and Albee 1955; Dassonville and Bala 2004; Dassonville et al. 2004; de Grave et al. 2002; Dietzel 1924; Roelofs 1935). This effect is commonly referred to as the “Roelofs effect”. Other visual stimuli are similarly displaced, an effect termed the “induced Roelofs effect”.

Experiment 2 was undertaken to determine if the Roelofs effect or induced Roelofs effect contributed to the egocentric localization effects in the pointing results of Experiment 1. Specifically, pointing measures were obtained for both the IM and flashed targets with a *static* surround presented in either the left or right terminal positions of the surround used in Experiment 1.

Method

Subjects

The subjects were the same as in Experiment 1. The research was approved by the ethics committee at the University of California at Davis and therefore accords with the 1964 Declaration of Helsinki. All subjects gave their informed consent prior to inclusion.

Apparatus

The apparatus was the same as in Experiment 1.

Procedure

Subjects participated in one experimental session that was similar to the Pointing session of Experiment 1. At the beginning of the session, a baseline pointing measure was obtained with the room lights on in the same manner as in Experiment 1. Following the baseline measures, pointing accuracy was assessed for both the IM and flashed targets (as termed in Experiment 1: there was no IM in Experiment 2). On each trial, the IM target and surround were presented for 2 s with the surround positioned 2.6 cm to either the left or right of the objective straight-ahead. These positions correspond to the terminal left-most and right-most locations of the moving surround in Experiment 1. Subjects fixated the IM target, and the flashed targets were flashed during the last 100 ms of stimulus presentation. Following this, the display was extinguished and subjects pointed to the perceived location of either the IM target or the bottom flashed target. Ten measures were obtained for trials on which the surround was in the rightward position and another ten with the frame in the leftward position. Two subjects performed the rightward trials first and the other two did the leftward trials first. Following these measures, 20 similar trials were conducted on which subjects pointed at the apparent location of the bottom of the two flashed targets that had been flashed immediately prior to offset, with the same order as for the IM targets.

Results

Error scores were calculated for each pointing response in the same manner as Experiment 1. These data were entered in a 2 (target: IM vs. Vernier) × 2 (surround displacement: left vs. right) ANOVA. There was no statistically significant main effect for target [$F(1,39) = 1.04$, $P > 0.05$]. The main effect of surround displacement was statistically significant, with mean pointing displaced to the right on surround-left trials relative to the surround-right trials [$F(1,39) = 54.30$, $P < 0.001$]. The interaction of target and surround offset was not statistically significant [$F(1,39) = 0.22$, $P > 0.5$]. Figure 4 shows the mean pointing error for both targets and surround displacements. It can be seen in the figure that the effect of surround displacement direction was similar for both IM and flashed targets.

Discussion

The primary finding of Experiment 2 was that pointing at both the IM and flashed targets was shifted similarly in the direction opposite the static surround displacement. Therefore, some of the effect observed in Experiment 1 that pointing was opposite the direction of immediately prior surround motion may be attributed to the eccentric location of the surround at offset. However, this finding cannot account for the dissociation found in Experiment 1, in

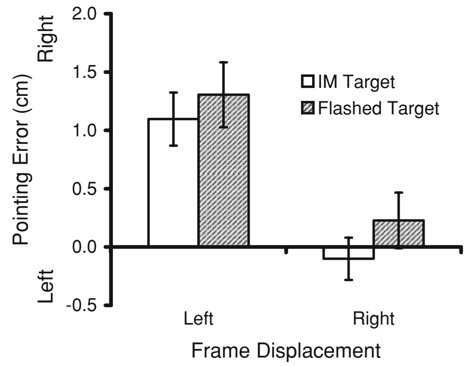

Fig. 4 Pointing errors in Experiment 2 for both IM and flashed targets and both directions of displacement of a static surround. *Error bars* correspond to ±1 SE

which the pointing effect was greater for the IM target than for the flashed target. The Roelofs effect is typically attributed to a shift of the subjective midline in the direction of the asymmetrical visual simulation (e g, Werner et al. 1953). Any such shift is assumed to cause the apparent egocentric location of all visual stimuli to be shifted equally in the opposite direction, hence the induced Roelofs effect (although de Grave et al. (2002) question this assumption) . However, the results of Experiment 1, and of Post and Welch (2004), demonstrate that the pointing effect is greater for the IM target than for other visual stimuli.

Experiment 3

In Experiment 1, the display was extinguished when the surround was at either the left-most or right-most extreme of its horizontal motion. Because for that instant the surround was stationary, it can be assumed that the IM target was likewise perceived as stationary.[4] It follows, therefore, that under this condition observers are unlikely to experience allocentric location displacement in the form of a flash-lag effect (e.g. MacKay 1958; Metzger 1932; Nijhawan 1994) or "movement-related positional bias" (DeValois and DeValois 1991).[5] But what if the conditions were arranged so that the target was perceived to be *moving* at the time of the egocentric and allocentric measures? Experiment 3 addressed this question by taking these measures when the surround was at or near the center of its oscillation, the point at which the perceived movement of the IM target is presumed to be maximal.

Method

Subjects

Eight right-handed volunteers (three males and five females), aged 19–51 years (mean 24 years), served as subjects. All had normal vision and were able either to focus at the distance of the displays without correction or could do so with contact lenses. Two subjects were familiar with the experimental hypotheses. The research was approved by the ethics committee at the University of California at Davis and therefore accords with the 1964 Declaration of Helsinki. All subjects gave their informed consent prior to inclusion.

Apparatus

The apparatus was the same as in Experiments 1 and 2.

Procedure

Subjects participated in two experimental sessions that were very similar to the Pointing and Vernier sessions of Experiment 1 and were separated by at least 1 day.

Pointing session

The Pointing session was identical to that of Experiment 1 except for the timing of the flashed targets, which were presented when the IM target was centered in the surround following two cycles of surround oscillation. This contrasts to the arrangement in Experiment 1 where the targets were presented when the surround was at the left or right endpoint of its oscillation (following 2.25 cycles of oscillation). In the present experiment, the flash began 50 ms before the surround had completed two cycles and continued until 50 ms after the two-cycle mark. As in Experiment 1,

[4] The IM target should be perceived as stationary at surround reversals if it is assumed that IM and surround motion are phase-locked. Evidence that IM is phase-locked (or nearly phase-locked) with surround motion is provided by studies where the IM target oscillates perpendicularly to surround sinusoidal oscillations (e.g., Gogel and Tietz 1976; Wallach et al. 1978; Post et al. 1989). Under these conditions, the IM target appears to move on a path that represents the vector sum of the physical motion with IM, and appears to travel in an essentially straight path, the slope of which can be matched by subjects. When a triangle wave, which has abrupt reversals in comparison with a sine wave, characterizes such stimulus oscillation, a small phase shift between IM and surround motion may be observed (Post and Chaderjian 1988).

[5] Because the anticipated future direction of IM is predictive at reversal points, the "motion extrapolation" hypothesis of the flash-lag effect (Nijhawan 1994) and the similar concept of "representational momentum" as discussed by Kerzel et al. (2001), might actually predict a small localization effect in the opposite direction of the previously seen IM. This effect would be opposite the obtained results of a localization effect in the same direction as the previously seen IM. The predicted effect would be very small, however, due to the low velocity of IM at the reversal point with a sinusoidally moving inducer.

the surround and IM target remained visible until the surround completed a total of 2.25 cycles, at which point they were extinguished. Subjects were instructed to point to the apparent location of the IM target at the time the flashed targets were flashed.

Vernier session

The Vernier sessions contained two conditions similar to the Surround Left and Surround Right conditions of Experiment 1, with the exception that the timing of the flashed targets was that used in the Pointing Session of Experiment 2 (i.e., the flash occurred when the IM target was close to the center of the rectangle). The conditions were termed "Surround Rightward" and "Surround Leftward", corresponding to the direction the surround was traveling at the time of the flash.

Results

Pointing session

Error scores were calculated for each pointing response as in Experiments 1 and 2. These error scores were entered into a 2 (target: IM vs. Vernier) × 2 (surround motion: leftward vs. rightward) ANOVA. There was no statistically significant effect of target [$F(1,79) = 0.01$, $P > 0.05$]. The effect of surround motion at flash was statistically significant [$F(1,79) = 16.91$, $P < 0.001$]. Pointing responses were .59 cm further to the right on surround rightward trials than on surround leftward trials. The interaction of target and surround motion was also statistically significant [$F(1,79) = 4.09$, $P < 0.05$]. Figure 5 shows the mean pointing error for both targets and surround motion directions. It is apparent in the figure that the difference between leftward and rightward surround motion is greater for the flashed target responses than for the IM target responses. This pattern is clearly opposite that obtained in Experiment 1.

Vernier session

Vernier judgments. The results obtained for the Vernier judgments are presented in Table 2. As in Experiment 1, Vernier judgments were evaluated with respect to whether the IM target was reported in its correct relationship to the flashed targets, or was subject to a rightward or leftward error. In the Surround Rightward condition, judgments were accurate on 167 of 192 trials (87% accuracy). Of the 25 incorrect judgments, 16 were rightward errors and 9 were leftward errors. In the Surround Leftward condition, judgments were accurate on 180 of 192 trials (94% accuracy). Of the 12 incorrect judgments, 5 were rightward errors and 7 were leftward errors. A 2 (surround direction) × 2 (error direction) chi-square analysis indicated that there was no statistically significant effect of surround motion on error direction [χ^2 (1) = 1.65, $P > 0.05$].

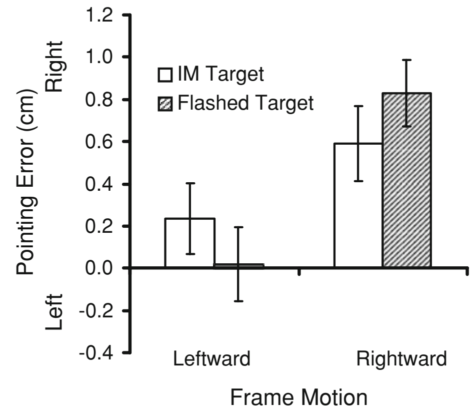

Fig. 5 Pointing errors in Experiment 3 for both IM and flashed targets and both directions of surround motion. *Error bars* correspond to ±1 SE

Table 2 Vernier judgments of Experiment 3: IM target was presented either aligned with two flashed targets or displaced 2 mm to the right or left for two conditions of surround motion

Surround motion	IM target displacement	Perceived displacement		
		Left	Centered	Right
Leftward	Left	63	1	0
	Aligned	4	56	4
	Right	0	3	61
Rightward	Left	57	7	0
	Aligned	2	53	9
	Right	0	7	57

Subjects reported the perceived location of the IM target relative to the flashed targets

Discussion

In Experiment 3, open-loop pointing at the IM target was biased in the same direction as surround motion. This result is clearly different from the effect observed in Experiment 1, where pointing was biased in the direction *opposite* the preceding surround motion.

It was previously stated that shifting inducers tend to produce apparent egocentric displacements of the IM target in the direction of the IM while non-shifting inducers do not. In Experiment 3, although the surround was shifting relative to the median plane, during the time interval that the flashed targets were actually flashed it was centered on the subject's median plane. Therefore, in this respect, the data might be expected to resemble those obtained with non-shifting inducers (Bacon et al. 1982; Brenner and Smeets 1994; Smeets and Brenner 1995). The present finding that pointing at the IM target is displaced in the same direction as surround motion implies that there is an important difference between the shifting but centered surround in the present study and the non-shifting and centered surrounds used in prior studies. One possibility is that the non-shifting inducers used in prior studies had well-defined boundaries that were stationary and centered on the subject's midline, whereas the inducer used in Experiment 3 did not have these characteristics. That is, the stationary boundaries used in these earlier displays may have provided a reference framework that suppressed any effect of inducer motion on the pointing responses.

The pointing responses obtained in Experiment 3 resemble those reported in other studies where pointing responses to a visual target were shifted in the same direction as the motion of a nearby stimulus (Brenner and Smeets 1997; Gomi et al. 2006; Mohrmann-Lendla and Fleischer 1991; Saijo et al. 2005; Whitney et al. 2003). This effect, termed the "manual following response" (MFR) (Saijo et al. 2005), has been shown to depend on the duration of the target (Whitney et al. 2003), the magnitude of the MFR decreasing with increased target duration. In the present study, the IM target was continuously visible while the flashed targets were flashed for 100 ms. Therefore, a greater MFR would be expected for the flashed targets than for the IM target, consistent with the obtained results.

As in Experiment 1, the results of the Vernier task displayed no effect of IM on perceived allocentric location. Because the effect of surround motion on pointing was .45 cm greater for the flashed target than for the IM target, the Vernier results would have been significantly different if the egocentric results also applied to the allocentric Vernier measures. Therefore, the egocentric results cannot account for the allocentric data.

The failure of surround motion (hence IM) to influence Vernier judgments demonstrates that perceived motion of a stimulus is insufficient to produce an apparent displacement of the stimulus relative to other flashed stimuli analogous to the flash-lag effect (e.g. MacKay 1958; Metzger 1932; Nijhawan 1994). In this regard, the present findings are similar to those of Nijhawan (2001), who investigated the flash-lag illusion during pursuit eye movements in which fixation was maintained on a stimulus perceived to be moving, and found no evidence of a flash-lag effect. Similarly, the lack of a Vernier effect suggests that illusions such as representational momentum (Freyd and Johnson 1987; Kerzel et al. 2001) and the onset repulsion effect (Thornton 2002) are not responsible for the results.

Summary

In Experiment 1, pointing responses were displaced in the direction of the previously seen IM for the IM target and to a lesser degree for the bottom flashed target. However, the allocentric Vernier judgments demonstrated no perceptual displacement of the IM target relative to the flashed targets. Thus, egocentric location measures were dissociated from allocentric location measures. Contrary to most reports of vision–action dissociation, the current perceptual measures were accurate while the motor measures were influenced by an illusion. In Experiment 2, pointing responses were displaced in the direction opposite displacement of an eccentric stationary surround. Unlike Experiment 1, the displacement of the pointing responses was similar for both the IM target and the bottom flashed target. Therefore the difference in pointing responses for the IM and flashed targets in Experiment 1 is attributable to IM. In Experiment 3, egocentric pointing responses were displaced in the direction of surround motion (opposite IM) for the IM target and to a greater degree for the bottom flashed target. However, there was no apparent displacement of the IM target relative to the flashed targets in the allocentric Vernier judgments. Therefore, in both Experiments 1 and 3 egocentric location measures were dissociated from allocentric location measures.

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