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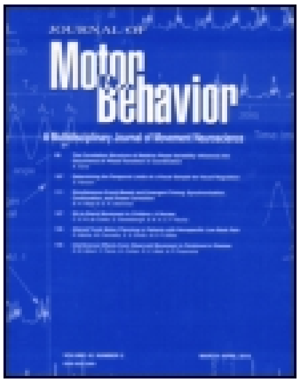

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Egocentric and Allocentric Visual Cues Influence the Specification of Movement Distance and Direction

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ABSTRACT. The authors investigated whether visuomotor transformations that support the computation of movement distance (i.e., extent) and movement direction rely differentially on integration of egocentric and allocentric visual information. To accomplish that objective, the authors factorially arranged 17 participants' open-loop reaching movements from 2 movement-start locations with mediolateral (ML) and anteroposterior (AP) variants of the induced Roelofs effect (IRE). The 2 movement-start locations in combination with the 2 IRE configurations enabled the authors to examine the impact of illusory movement pertaining to distance (i.e., AP-IRE) and direction (i.e., ML-IRE) information. AP-IRE and ML-IRE configurations across the 2 movement-start locations reliably influenced reaching endpoints in a direction consistent with the perceptual effects of the illusion. These findings suggest that unitary visual information involving interactive egocentric and allocentric visual cues supports the specification of both movement distance and movement direction.

Keywords: allocentric, egocentric, illusion, induced Roelofs effect, open-loop, reaching

Researchers can predict the position of an object in peripersonal space with respect to the body (the so-called egocentric frame of visual reference) or relative to contextual features and other objects (the so-called allocentric frame of visual reference). An issue of current debate in the visuomotor neurosciences involves the extent to which those frames of visual reference influence visually derived reaching and grasping movements.[1] On the one hand, in their influential perception–action model (PAM), Goodale and Milner (1992; see also Milner & Goodale, 1995) asserted that metrical (i.e., Euclidean) visual information specified in a strictly egocentric frame of visual reference supports visually derived action. According to the PAM, the use of allocentric visual information is limited to situations involving perception- or memory-based activities (for a review, see Goodale, Westwood, & Milner, 2004). Behavioral support for that view stems from the results of some studies that showed that pictorial illusions reliably trick perceptions, whereas visually derived actions are mostly—if not entirely—immune to illusory information (e.g., Aglioti, DeSouza, & Goodale, 1995; Brenner & Smeets, 1995; Haffenden & Goodale, 1998; Westwood, Heath, & Roy, 2000). However, results reported in a growing literature have suggested that integrative egocentric and allocentric visual cues support the sensorimotor transformations underlying motor output (e.g., Heath, Rival, Neely, & Krigolson, 2006). Support for this view has also been garnered from the pictorial illusions literature and from the finding that contextual features similarly influence perceptions and actions (Elliott & Lee, 1995; Franz, 2003; Gentilucci, Chieffi, Daprati, Saetti, & Toni, 1996; Heath, Neely, & Binsted, 2007; Heath, Rival, & Binsted, 2004; Heath, Rival, & Neely, 2006; Mendoza, Elliott, Meegan, Lyons, & Welsh, 2006; for a review, see Glover, 2004).

In reconciling the aforementioned discrepant findings, one should note that a component parameter, or parameters, may determine the extent to which pictorial illusions influence actions. For example, researchers have shown that the spatial orientation of an illusion (e.g., Coello, Richaud, Magne, & Rossetti, 2003) and the nonillusory structure surrounding a target (Krigolson, Clark, Heath, & Binsted, 2007) can influence the extent to which allocentric cues affect motor output. In the present investigation, we used an exemplar pictorial illusion (i.e., the induced Roelofs effect [IRE]) to address how the orientation of an illusion

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with respect to a movement-start position (and ensuing trajectory of a goal-directed reaching response) impacts the nature of the visual information that supports visually derived actions.

The IRE involves a visual background in which researchers typically present a luminous target within a centered, offset-left, or offset-right frame (e.g., ±5°) and ask participants to perceptually judge (e.g., verbally report or make a forced-choice response) the position of the target or complete a goal-directed reaching response to that target location. In initial studies, Bridgeman, Peery, and Anand (1997) reported that the IRE robustly influences perceptual judgments of target location in that offset-left and offset-right frames induce a misperception of target location opposite the direction of the frame shift. In contrast, they concluded that immediate jabbing movements were immune to the IRE's illusion-inducing properties (see also Bridgeman, Gemmer, Forsman, & Huemer, 2000). According to Bridgeman et al. (2000), and in line with duplex models of visual processing (i.e., the PAM), the IRE tricks perceptions because top-down cognitive processes rely on obligatory information related to the entire visual scene (i.e., allocentric visual cues). In contrast, visually derived actions are immune to illusory information because people use visual information concerning the absolute position of a target with respect to themselves (i.e., egocentric visual cue) for such responses.

In studies of the IRE, researchers traditionally present the long-axis of the frame surrounding the target mediolateral (ML) to the observer (i.e., ML-IRE; see Figure 1). In fact, researchers who have used the ML-IRE have consistently concluded that the mediolateral frame orientation

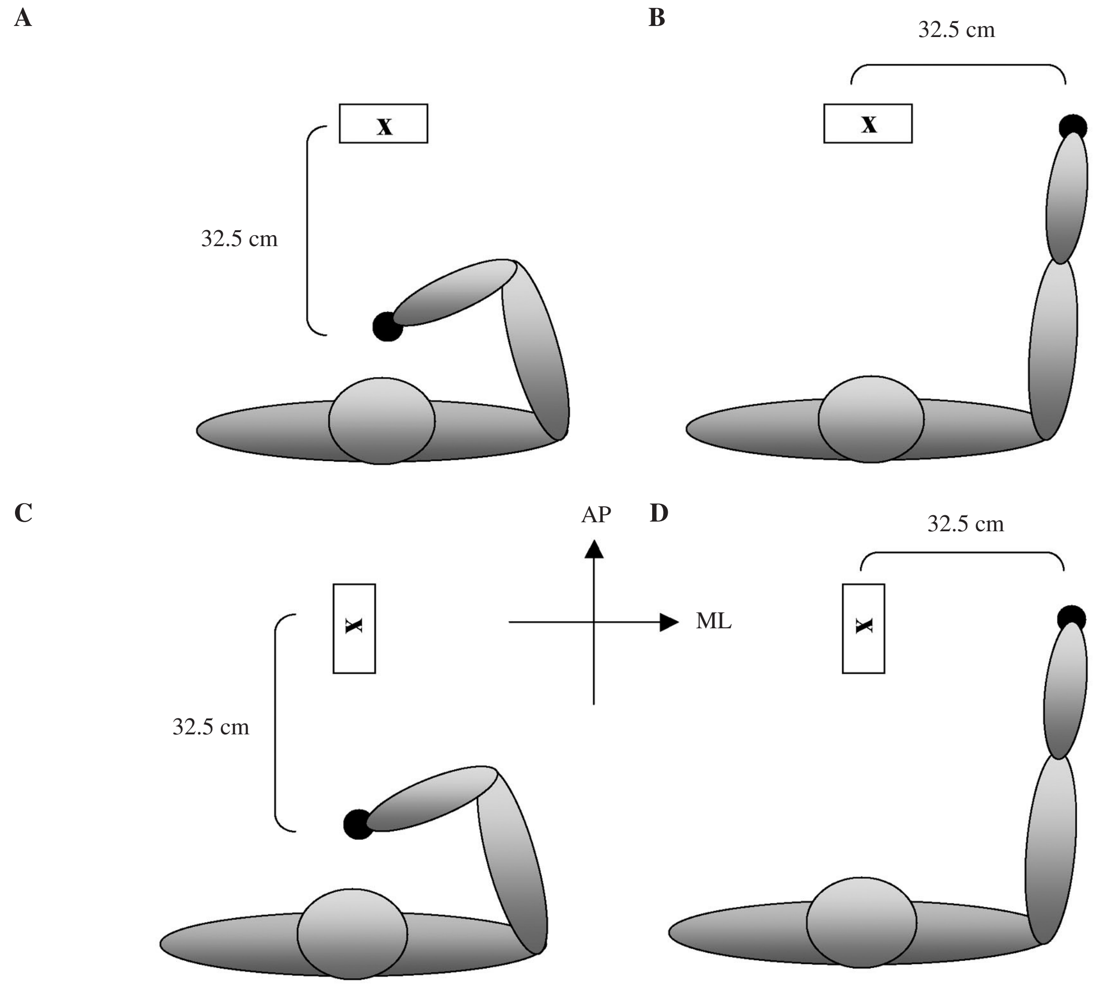

FIGURE 1. Bird's-eye view of the relationship between movement-start location and mediolateral (ML) and anteroposterior (AP) induced Roelofs effect (IRE) orientations. The midline target associated with the centered ML-IRE is depicted for (**A**) AP-start locations and (**B**) ML-start locations. The middle target associated with the centered AP-IRE is shown for (**C**) AP-start and (**D**) ML-start locations. In all examples, the length of the start position to the target vector was 32.5 cm. The spatial arrangements that Coello et al. (2003) used are shown in (**A**) and (**C**).

influences perceptions but not visually derived actions (Bridgeman et al., 2000; Bridgeman & Huemer, 1998; Bridgeman et al., 1997; Dassonville, Bridgeman, Bala, Thiem, & Sampanes, 2004). It is interesting to note, however, that Coello et al. (2003) indicated that visuomotor resistance to the IRE depends on the illusion's spatial orientation. In their study, participants completed reaches from a common home position (i.e., a midline start position) to a traditional orientation of the IRE (i.e., ML-IRE) and to a condition in which the long-axis of the frame was anteroposterior (AP) to the performer (i.e., AP-IRE; see Figure 1). Their use of that manipulation was motivated by the hypothesized independence of visuomotor channels responsible for the specification of movement distance and movement direction (Gordon, Ghilardi, & Ghez, 1994) and the claim that each channel may differentially integrate egocentric and allocentric visual cues. The results of the Coello et al. study showed that reaches were immune to the ML-IRE but not the AP-IRE. Thus, typical perceptual misjudgments of veridical target direction opposite to the frame shift did not translate into direction error in specification of reaching trajectories. For the AP-IRE, however, perceptual responses and specification of movement distance were influenced in a direction opposite to the frame shift. The findings of Coello et al. suggest that egocentric visual cues support specification of movement direction, whereas interacting egocentric and allocentric visual cues serve the coding of movement distance. In other words, distinct visual information mediates movement distance and movement direction.

The findings of Coello et al. (2003) represent an interesting framework for understanding proposed interactions between egocentric and allocentric cues and their singular or shared influence on the specification of movement distance and direction. There is, however, an important issue for researchers to reconcile from their work. That issue relates to the orientation of the illusion with respect to movement-start location and the ensuing primary axis of reaching responses. As we mentioned earlier, Coello et al. used a common start location for reaching movements (see Figure 1). Given that setup, the primary movement axis of the AP-IRE was congruent with the long-axis of the frame surrounding the target (i.e., the illusion-inducing element of the IRE), whereas the primary movement axis of the ML-IRE was orthogonal to the long-axis of the frame. We raise this as an important issue because de Grave, Brenner, and Smeets (2004b) observed that contextual features surrounding movement endpoint influenced reaching movements along the shaft of the Brentano illusion but not reaches orthogonal to the shaft. The results of de Grave et al. suggest that the relation between movement-start location and the orientation of an illusion plays a fundamental role in determining the extent to which actions are refractory or are tricked by pictorial illusions. Thus, with regard to the Coello et al. study, it is unclear whether the spatial orientation of the IRE alone or the orientation of the illusion with respect to the movement-start position (and primary axis of a reaching response) influenced the degree to which egocentric and allocentric visual cues interacted to influence the computation of biased movement distance.

In the present investigation, we examined the contemporaneous influences of movement-start position and spatial orientation of the IRE to determine whether egocentric and allocentric visual cues differentially influence the specification of movement direction and distance. Participants made perceptual judgments of target location within ML-IRE and AP-IRE configurations. In addition, we factorially combined visually derived reaches (specifically, open-loop reaches) to ML-IRE and AP-IRE configurations with two movement-start locations to produce concordant or discordant spatial relations between the long-axis of the illusion and the primary axis of reaching responses. We reasoned that such a manipulation would provide a basis for determining if the spatial orientation of the IRE per se or the relationship between movement-start position and the orientation of the IRE affects the frame, or frames, of visual reference that the visuomotor system uses to support the computation of movement distance and direction.

Method

Participants

Participants were 17 students from Indiana University. All were right-hand dominant, had normal or corrected-to-normal vision, and were naive to the hypothesis being tested. All participants gave informed consent, and the Human Subjects Committee, Indiana University, approved this study.

Apparatus and Stimuli

We used an apparatus similar to that introduced by Held and Gottlieb (1958; see Figure 2). The apparatus consisted of a virtual environment contained within a rectangular box (74 cm high × 96 cm wide × 60 cm deep) that was divided in half by a one-way mirror. We kept constant the difference in height (a) between the monitor and mirror and (b) between the mirror and the lower surface of the apparatus (i.e., 37 cm). We placed a 17-in. LCD Dell computer monitor (Model E171FP) upside down on the top shelf of the apparatus to project visual stimuli on the surface of the mirror. Visual stimuli projected on the surface of the mirror appeared to be located on the lower surface of the apparatus. We smoothed all internal surfaces of the apparatus and painted them matte black. The participant sat at an open end of the apparatus for the duration of the experiment. We stabilized his or her head with a head and chin rest (Lafayette Instruments, Lafayette, IN; Model 14302). The distance between the aiming surface and the horizontal bar of the head and chin rest was approximately 50 cm.

We used ML-IRE and AP-IRE IRE configurations (see Figure 3). For the ML-IRE, we projected a 19-cm-wide × 8.5-cm-high white rectangular frame against a high-contrast black background and (a) centered the frame to the

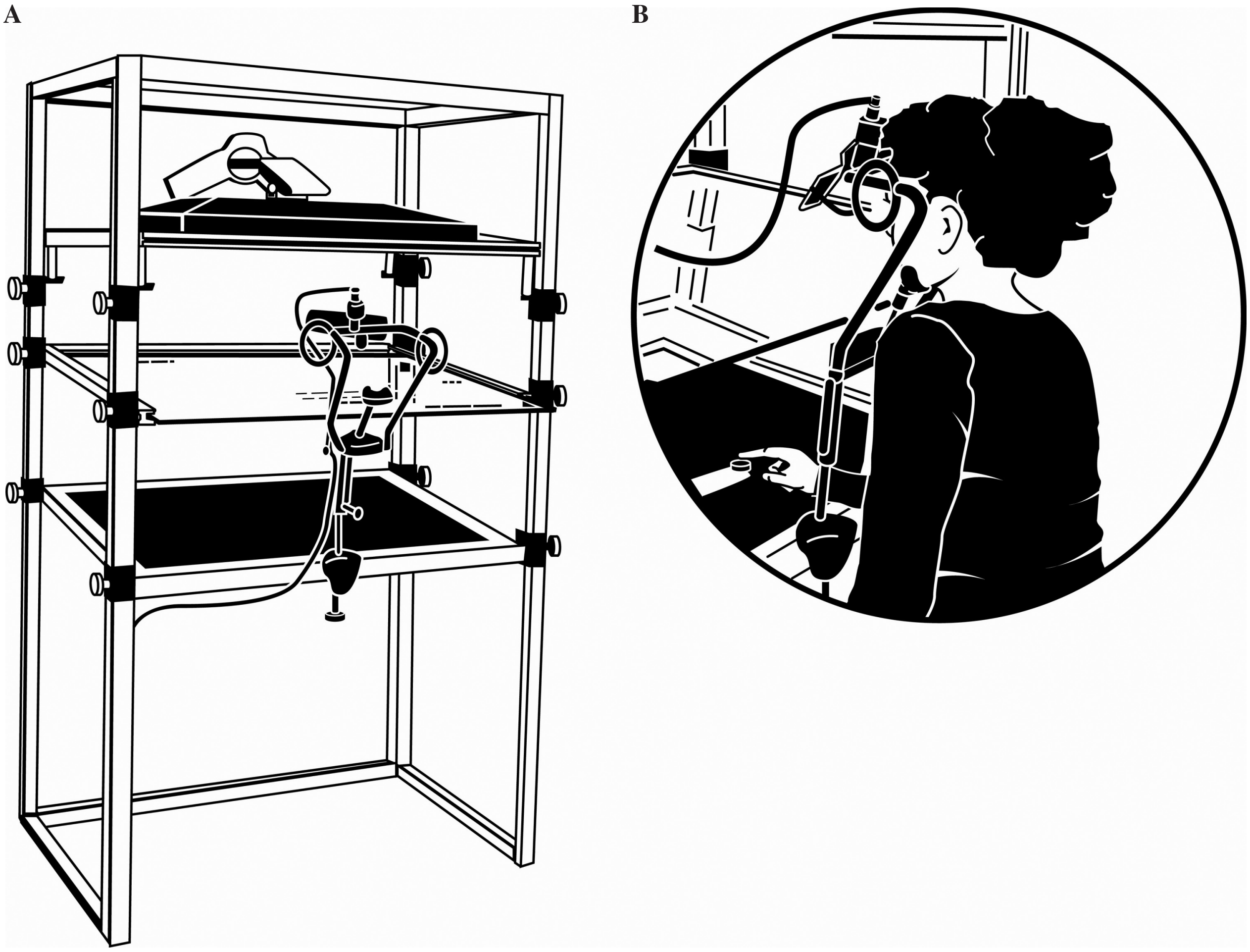

FIGURE 2. Schematics of the experimental apparatus. In (**A**), the upper shelf that supported the computer monitor can be seen. In (**B**), a participant who is using the apparatus is shown.

participant's midline, (b) shifted the frame 2 cm to the right (i.e., offset right), or (c) shifted the frame 2 cm to the left (i.e., offset left) of midline. For the AP-IRE, we used the same frame. However, we rotated the long-axis of the frame 90° with respect to the long-axis that we used in the ML-IRE condition. Accordingly, we projected the frame associated with the AP-IRE configuration in (a) a centered position, (b) a position shifted 2 cm proximally (offset proximal), or (c) a position shifted 2 cm distally (offset distal). Targets were 3-mm-high white crosses (i.e., an X) that we presented at three locations within each IRE configuration. As shown in Figure 3, we refer herein to the three targets associated with the ML-IRE configuration as *left*, *midline*, and *right* targets. For the AP-IRE configuration, we refer to targets as *far*, *middle*, and *near*.

For the reaching task (see Procedure), a microswitch served as the home position. In addition, we affixed a splint complex that included dual light-emitting diodes (LEDs) to the nail of the right index finger (i.e., the pointing finger). The LEDs enabled us to manipulate limb vision without altering light levels in the experimental suite. We controlled visual and auditory events by using Eprime Version 1.1 (Psychology Software Tools, Pittsburgh, PA).

Procedure

Perceptual task. We concurrently projected target and frame for 250 ms, and we then presented a blank screen for an additional 250 ms. After the 250-ms interstimulus interval, we presented a virtual ruler (overlaying the target area) consisting of 20 white vertical marks, each representing one whole number, directly over the target area. As shown in Figure 3, we labeled the ruler with numbers –10, –5, 0, 5, and 10. Those values, which served as numeric identifiers and veridical target locations (in both ML-IRE and AP-IRE configurations), corresponded to positions –2.5, 0, and 2.5 on the virtual rulers. For each trial, participants used the virtual ruler to verbally report target location. We presented the ML-IRE and AP-IRE configurations in separate trial blocks, with the order of block randomized. We pseudorandomly presented the factorial arrangement of frame orientations (e.g., offset left, centered,

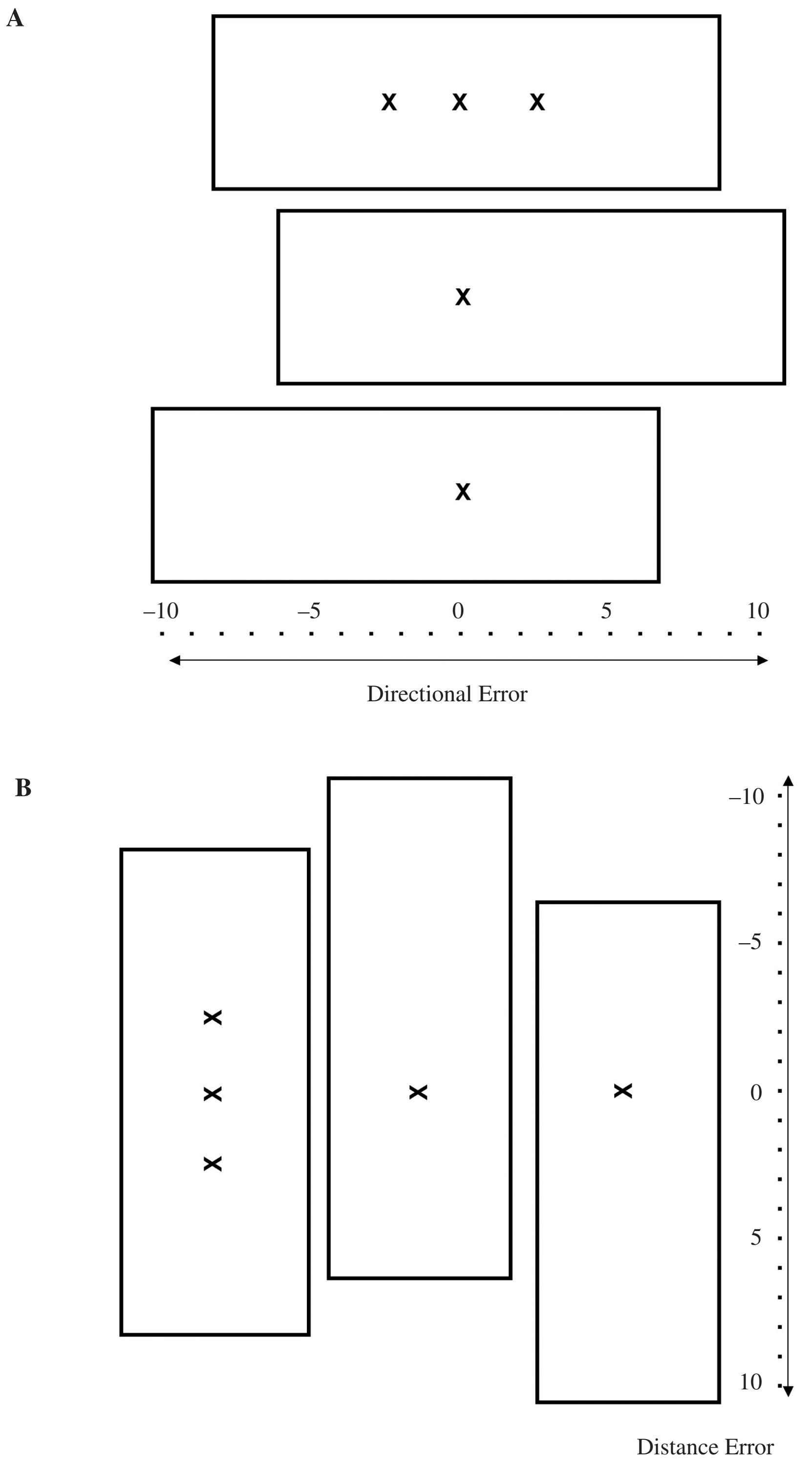

FIGURE 3. (**A**) Mediolateral induced Roelofs effect (ML-IRE) and (**B**) anteroposterior induced Roelofs effect (AP-IRE) configurations used in the present investigation. Three target positions were associated with each IRE configuration: For the ML-IRE, target positions were referenced with respect to participants' body midline (i.e., left, midline, and right), whereas for the AP-IRE, target positions were referenced with respect to their distance in the depth plane (i.e., far, middle, near). Representations of the virtual rulers participants used to verbally report target distance and direction are also shown.

offset right; offset proximal, centered, offset distal) and target locations (e.g., left, midline, right; far, middle, near) within each IRE configuration. Participants completed five trials to each frame orientation and target location for a total of 90 perceptual trials.

Reaching task. We used the same ML-IRE and AP-IRE configurations for the reaching task. When participants placed their pointer finger on the home position microswitch, they initiated reaching trials. That action illuminated the LEDs attached to the splint complex (which remained visible throughout a trial) and resulted in projection of the visual stimuli for 250 ms. After that point, we cued participants (via auditory tone) to execute quick and accurate pointing movements to the target. The IRE remained visible until release of pressure from the home position microswitch. Therefore, the IRE was visible during response planning but not during response execution (open-loop pointing).

Participants completed reaches from an ML movement-start location and an AP movement-start location (ML-start and AP-start, respectively). Figure 1 shows that the ML-start location was 32.5 cm to the right of participants' midline and 40 cm anterior to the front edge of the aiming apparatus. The movement-start location was concordant with the long-axis of the ML-IRE. The AP-start location was located at participants' midline and 7.5 cm from the front edge of the aiming apparatus and was concordant with the long-axis of the AP-IRE. We factorially combined ML-start and AP-start locations with ML-IRE and AP-IRE configurations.

Participants completed the Movement-Start × IRE Configuration combinations (i.e., ML-start/ML-IRE, ML-start/AP-IRE, AP-start/AP-IRE, AP-start/ML-IRE) in separate, randomly ordered trial blocks. Participants completed five trials for each of the Frame Orientation (offset left, centered, offset right; offset proximal, centered, offset distal) × Target Position (left, midline, right; far, middle, near) combinations (which we ordered pseudorandomly). Thus, across the four trial blocks, participants completed 180 reaching trials.

Data Collection and Reduction

Perceptual task. We recorded participants' verbal reports of target location, and we used those reports to compute constant error (*CE*). For the ML-IRE configuration, participants reported target location in the ML plane (i.e., direction accuracy); hence, positive and negative *CE*s, respectively, represented leftward and rightward errors with regard to veridical target direction. In the AP-IRE configuration, participants completed verbal reports on target location in the AP plane (i.e., distance accuracy). Positive and negative *CE*s, respectively, in that condition represented over- and underestimations of veridical target distance.

Reaching task. The splint complex attached to the pointer finger (i.e., the right index finger) contained, in addition to dual LEDs, an infrared-emitting diode (IRED). We used an OPTOTRAK 3020 motion analysis system (Northern Digital Inc., Waterloo, Ontario, Canada) to sample IRED position data at 200 Hz for 1.5 s following the auditory initiation cue. We filtered displacement data offline by using a second-order dual-pass Butterworth filter with a low-pass cutoff frequency of 15 Hz. We defined *movement onset* as the first frame in which velocity exceeded 50 mm/s for 10 consecutive frames (i.e., 50 ms) and *movement offset* as the first of 10 consecutive frames in which velocity was less than 50 mm/s. We computed instantaneous velocities by differentiating displacement data via a three-point central finite difference algorithm. Dependent variables included *reaction time* (*RT*; i.e., the time from response cuing to movement onset) and *movement time* (*MT*; i.e., the time from movement onset to movement offset). In line with the perceptual task, we measured *CE* for reaching movements with respect to the long-axis of the IRE configuration. Thus, we measured endpoint accuracy for reaches in the ML-start/ML-IRE and AP-start/ML-IRE conditions in the ML plane, with positive and negative *CE*s reflecting respective leftward and rightward endpoint errors relative to veridical target direction. For the ML-start/AP-IRE and AP-start/AP-IRE conditions, we measured *CE* in the AP plane, with positive and negative *CE* values reflecting over- and undershooting of veridical target distance, respectively.

Data Analysis

For the perceptual task, we calculated *CE* for all verbal responses and submitted the results for the AP-IRE and ML-IRE configurations to separate 3 (frame position: offset-left/distal, centered, offset-right/proximal) × 3 (target eccentricity: left–far, midline–middle, right–near) repeated measures analysis of variance (ANOVA).[2] For the motor task, we conducted separate ANOVAs for each combination of movement-start location and IRE configuration and submitted dependent variables to the same ANOVA model ($\alpha = .05$). We examined the highest order power polynomial to decompose significant main effects (Pedhazur, 1997).

Results

Perceptual Task

The analyses of perceptual bias (*CE*) revealed main effects for frame position, $Fs(2, 32) = 16.85$ and 5.37, $ps <$ .001 and < .01, respectively, and target eccentricity, $Fs(2, 32) = 12.31$ and 22.31, $ps < .01$ and < .001, respectively, for AP-IRE and ML-IRE. As shown in Figure 4, the offset-distal and offset-proximal frames of the AP-IRE resulted, respectively, in under- and overestimation of veridical target distance (only linear effect significant), $F(1, 16) = 13.82$, $p < .001$. For the ML-IRE, the offset-left frame enhanced rightward bias of veridical target direction relative to that of the offset-right frame (only linear effect significant), $F(1, 16) = 5.98$, $p < .03$. In terms of the effect of target eccentricity, *CE* in the AP-IRE configuration decreased linearly across the near to far targets (only linear effect significant),

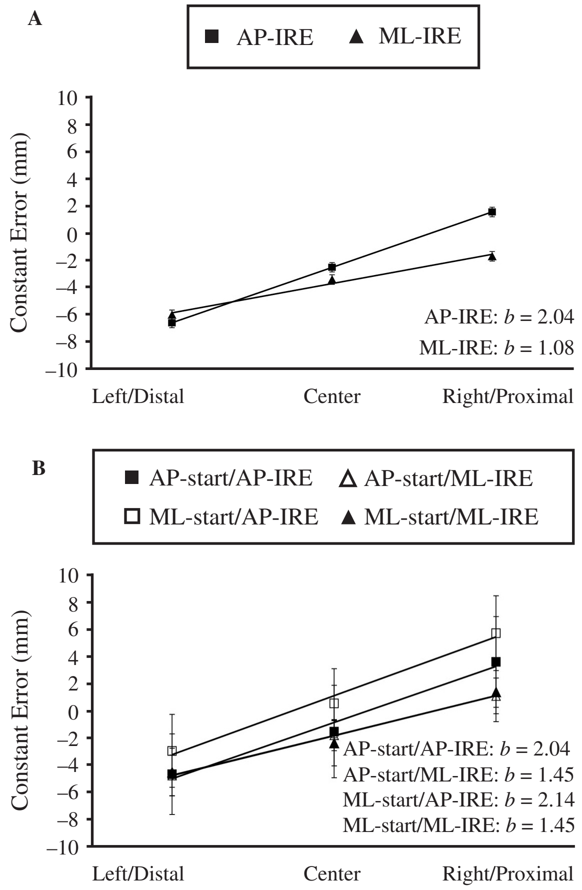

FIGURE 4. (**A**) Constant error (mm) for the perceptual task as a function of the mediolateral induced Roelofs effect (ML-IRE) and the anteroposterior induced Roelofs effect (AP-IRE) configurations. (**B**) Constant error (mm) for the reaching task plotted as a function of movement-start (i.e., ML-start or AP-start) and IRE configuration (ML-IRE or AP-IRE). The slope of the regression line (*b*) for each movement-start and IRE configuration is shown. The ML-start/ML-IRE trend line obscures the AP-start/ML-IRE trend line. Error bars indicate standard error of the mean.

F(1, 16) = 14.51, *p* < .001. For the ML-IRE configuration, *CE* for the left target was less than *CE* for the right or the middle targets (significant quadratic effect), *F*(1, 16) = 22.31, *p* < .001.

Reaching Task

The analyses of reaching endpoint bias (*CE*) revealed effects for frame position for each of the Movement Start × IRE Configuration combinations, all *p*s < .001 (see Table 1 for ANOVA summary). Figure 4 shows that reaching endpoints across each experimental context were biased in a direction consistent with the perceptual effects of the IRE. Thus, the offset-distal and offset-proximal frames associated with the AP-IRE configuration produced respective under- and overshooting of veridical target distance, and we observed that effect for AP-start and ML-start locations (only linear effects significant), *F*s(1, 16) = 37.94 and 47.51, respectively, *p*s < .001. Similarly, the offset-left and offset-right frames associated with the ML-IRE configuration resulted in reaching endpoints biased, respectively, right and left of veridical target location—irrespective of AP-start and ML-start locations (only linear effects significant), *F*s(1, 16) = 14.77 and 9.34, respectively, *p*s < .01. We also observed an effect for target eccentricity in the ML-start/ML-IRE condition, *F*(2, 32) = 5.86, *p* < .01: Endpoints to the right target (–6.60 ± 3.0 mm) elicited greater rightward bias than did endpoints to the midline target (–3.22 ± 1.7 mm). In turn, endpoints to the left target (3.60 ± 2.3 mm) elicited a leftward bias (only linear effect significant), *F*(1, 16) = 6.11, *p* < .03.

TABLE 1. ANOVA Summary of Main Effects of Frame Position for Each Movement-Start Position × Induced Roelofs Effect (IRE) Orientation Associated With the Reaching Tasks

Start Position × IRE Orientation	*F*(2, 32)
ML-Start × ML-IRE	8.30*
ML-Start × AP-IRE	38.94*
AP-Start × AP-IRE	28.16*
AP-Start × ML-IRE	11.06*

Note. ANOVA = analysis of variance. ML = mediolateral. AP = anteroposterior.
*$p < .001$.

RT and MT

We did not observe any effects or interactions involving RT (grand *M* = 203 ± 11 ms). However, the results for MT elicited main effects for target eccentricity in the AP-start/AP-IRE, ML-start/AP-IRE, and ML-start/ML-IRE conditions, *F*s(2, 32) = 15.54, 12.63, and 20.62, *p*s < .001. In the former two conditions, MT increased linearly from the near target to the far target; in the latter condition, MT increased linearly across the right target to the left target (only linear effects significant), *F*s(1, 16) = 32.91, 20.95, and 30.16, *p*s < .001 (see Table 2 for MT means).

Comparing Perceptual and Motor Tasks

To contrast the effect of the IRE on perceptual and motor responses, we individually computed the slopes of *CE* regression functions across the different frame orientations for each participant (see also Heath, Rival, & Binsted, 2004). We submitted perceptual and motor (AP-start/AP-IRE and ML-start/AP-IRE) values for the AP-IRE to one-way repeated measures ANOVA. We used the same ANOVA model to contrast the perceptual and motor (ML-start/ML-IRE, AP-start/ML-IRE) values of the ML-IRE. As demonstrated in Figure 4, AP-IRE and ML-IRE configurations demonstrated comparable illusion effects across perceptual and motor tasks, *F*s(1, 16) < 1.0.

TABLE 2. Mean ± Standard Error of Measurement of Movement Time (ms) as a Function of Movement-Start Position, IRE Orientation, and Target Eccentricity

Start position/IRE orientation	*M*	*SEM*	*M*	*SEM*	*M*	*SEM*
	Left		*Midline*		*Right*	
ML-start/ML-IRE	516	22	507	23	489	22
AP-start/ML-IRE	522	22	518	22	519	22
	Far		*Middle*		*Near*	
ML-start/AP-IRE	526	26	516	27	499	24
AP-start/AP-IRE	542	22	529	25	512	24

Target eccentricity spans the *M*/*SEM* columns.

Note. AP = anteroposterior; IRE = induced Roelofs effect; ML = mediolateral.

Discussion

AP-IRE and ML-IRE Configurations Trick Perceptual Judgments

When participants judged target location relative to a scene-based exemplar (i.e., the virtual ruler), AP-IRE and ML-IRE configurations influenced their perception of target location in the direction opposite to the frame shift. More specifically, when the long-axis of the IRE was offset proximally or distally in the AP plane (AP-IRE), participants over- or underestimated target distance, respectively (e.g., Coello et al., 2003). When the frame was offset left or right in the ML plane (ML-IRE), participants misperceived target direction, with greater rightward bias in the offset-left frame orientation (Bridgeman et al., 2000; Bridgeman et al., 1997; Dassonville & Bala, 2004; Dassonville et al., 2004; de Grave, Brenner, & Smeets, 2004a). Most interesting, and despite that the ML-IRE influenced perceptual judgments in the direction opposite to the frame shift, we observed a rightward bias (i.e., negative *CE* value) regardless of the frame orientation. Although the precise nature of this direction-specific bias is beyond the scope of the present article, enhanced processing of context-dependent visual features in the right visual field (Fukusima & Faubert, 2001; Radoeva, Cohen, Corballis, Lukovits, & Koleva, 2005) may have contributed to that result. It is notable that the finding that both the AP-IRE and ML-IRE configurations tricked participants' verbal reports is consistent with the well-documented assertion that relative visual information specified in a necessarily allocentric frame of visual reference mediates perceptual judgments.

AP-IRE and ML-IRE Configurations Trick Reaching Movements

The open-loop reaching movements studied here provided participants with direct and egocentrically based visual information for real-time control of action (Westwood & Goodale, 2003).[3] Most interesting, and despite the salience of egocentric visual cues, participants' reaches were influenced in a direction consistent with the perceptual effects of the IRE. Moreover, neither the manipulation of IRE configuration nor the spatial relation between IRE configuration and movement-start location influenced the illusion's tricking of the actions. Thus, the endpoints of reaches to offset-proximal and offset-distal frames of the AP-IRE configuration produced respective over- and undershooting of veridical target distance regardless of whether movement-start position was concordant (AP-start) or discordant (ML-start) with IRE orientation. Similarly, the offset-left and offset-right frames of the ML-IRE configuration produced respective rightward and leftward directional biases for concordant (ML-start) and discordant (AP-start) movement-start positions.

Unitary Visual Representation for the Computation of Movement Distance and Movement Direction

As mentioned earlier, Coello et al. (2003) reported that reaches initiated from a common midline start location were susceptible to the AP-IRE but not the ML-IRE. The authors interpreted that dissociation as a reflection of the sensitivity of distance (i.e., extent) processing to the integration of allocentric visual information and the resistance of direction processing to contextual visual cues. In other words, Coello et al. proposed that computations of movement distance and movement direction are subserved by distinct visual representations. In the present investigation, we sought to disentangle whether the dissociation reported by Coello et al. is related to (a) the differential use of allocentric cues for the specification of movement distance and movement direction or (b) the spatial arrangement of the IRE with respect to movement-start location (e.g., de Grave et al., 2004a). To that end, we factorially combined AP-IRE and ML-IRE orientations with concordant or discordant movement-start locations. Regardless of the movement-start locations that we used here, it is notable that the AP-IRE and ML-IRE configurations reliably influenced movement endpoints.

The present findings are incongruent with the results reported by Coello et al. (2003). Moreover, our results provide no evidence for the assertion that the spatial orientation of the IRE relative to movement-start position influences visuomotor sensitivity to allocentric visual information. Instead, findings from the present work parallel those of a number of studies recently completed by our group (Heath et al., 2007; Krigolson et al., 2007; Krigolson & Heath, 2004; see also Binsted, Brownell, Vorontsova, Heath, & Saucier, 2007), which showed that contextual features—including illusory and nonillusory geometric structure—that surround a target facilitate both the distance and directional accuracy and stability of visually and memory-derived actions (see also Lemay, Bertram, & Stelmach, 2004). In fact, Krigolson and Heath proposed that vision of the limb (i.e., egocentric visual cue), in combination with contextual features surrounding a target (i.e., allocentric cues), provides a visual anchoring mechanism that facilitates the real-time or online distance and directional coding of a visually defined target or both (cf. Obhi & Goodale, 2005). Accordingly, the effect of the IRE across the different experimental conditions used here is in line with the view that interactive egocentric and allocentric visual information provides a unitary representation of the visual world (e.g., Franz, Fahle, Bülthoff, & Gegenfurtner, 2001). Thus, we propose that the computation of both movement distance and movement direction is mediated by a single and context-dependent visual representation.

We should emphasize that both the AP-IRE and the ML-IRE configurations influenced the reaches studied here. Furthermore, the effect of the illusion was on par with that observed for the perceptual task. Although the present findings are inconsistent with the strict dissociation between perceptions and actions predicted in the PAM (Goodale & Milner, 1992; for recent review, see Goodale et al., 2004), they are congruent with reports in a growing literature that visually derived actions can be influenced in a direction consistent with the perceptual effects of pictorial illusions (e.g., Daprati & Gentilucci, 1997; Elliott & Lee, 1995; Franz et al., 2001; Heath, Rival, & Binsted, 2004; Westwood, McEachern, & Roy, 2001; for recent reviews, see Glover, 2004; Mendoza, Hansen, Glazebrook, Keetch, & Elliott, 2005). Thus, our results provide accumulating evidence that leads us to question the extent to which the pictorial-illusions literature provides explicit behavioral evidence of dissociation of perceptions and actions.

Real-Time Movement Control and the IRE

A secondary issue that merits discussion concerns a challenge to the widely held view that visually derived actions are refractory to the traditional IRE orientation (i.e., ML-IRE). In fact, among the pictorial illusions that researchers have used to examine the hypothesized dissociation between perceptions and actions (e.g., Ebbinghaus/Titchener circles; Brentano, Judd, Müller–Lyer figures; rod-and-frame illusion; Glover, 2004), only in work involving the IRE have researchers consistently concluded that there are null illusory effects on the endpoints of visually derived reaches. Bridgeman et al. (2000; Bridgeman & Huemer, 1998; Dassonville et al., 2004; see also Coello et al., 2003), in particular, have concluded that "immediate responses" (Dassonville et al., p. 604) are not influenced by the IRE, and that conclusion has frequently been cited in the literature as strong support for duplex visual processing and for the assertion that real-time visual information entails the specification of metrical object information in a strictly egocentric frame of visual reference. It is, however, important to note that close scrutiny of the original investigation of Bridgeman et al. (1997), which involved immediate jabbing movements, reveals that such a conclusion is not straightforward. In fact, in Experiment 1 of that study, they reported, "5 subjects showed a highly significant Roelofs effect [$F(2, 4) > 18$, $p < .01$], whereas the other 5 showed no sign of an effect [$F(2, 4) < 3.16$, $p > .18$]" (p. 460). Of course, one cannot use that result as explicit evidence that visually derived responses rely on restrictive egocentric visual cues for motor output. Instead, the work of Bridgeman et al. (1997) and the results presented here highlight the view that contextual features of the IRE influence visually derived reaches.

It is possible that one or a number of between-experiment differences in methods may explain why some authors (but not the present ones) in the IRE literature (Bridgeman et al., 2000; Bridgeman & Huemer, 1998; Bridgeman et al., 1997; Dassonville et al., 2004; see also Coello et al., 2003) have generally concluded that visually derived responses are immune to the illusion's contextual features. However, we have not been able to identify a specific experimental factor that might account for the identified difference in outcome between our work and the general findings of Bridgeman et al. (2000; Bridgeman & Huemer, 1998; Dassonville et al., 2004).[4] Moreover, in the present investigation we used a pure open-loop reaching environment so that the IRE was visible to participants during movement planning and was occluded only after movement initiation (i.e., after release of pressure from the home position microswitch). In contrast, Bridgeman and colleagues used a technique in which occlusion of the IRE served as the movement imperative. Hence, the IRE was not visible to participants during movement planning. Coello et al. (2003) used a similar technique wherein vision of the IRE was not consistently available to participants throughout movement planning.[5] On the basis of extant findings, researchers would have expected our open-loop condition to elicit greater visuomotor resistance to the IRE because metrical visual limb and target information was available to participants to support real-time movement-planning processes (e.g., Heath, 2005; Heath & Westwood, 2003; Heath, Westwood, & Binsted, 2004; Westwood, Heath, & Roy, 2000, 2003; Westwood et al., 2001; for details of real-time movement planning, see Westwood & Goodale, 2003). Thus, the present results provide the first demonstration that open-loop reaching movements and, more generally, real-time movement-planning processes are influenced by the illusion-evoking properties of the IRE.

Conclusion

AP-IRE and ML-IRE orientations across both concordant and discordant movement-start locations influenced the endpoints of open-loop reaching movements. This finding contradicts the claim that allocentric visual cues exclusively influence computations of movement distance (Coello et al., 2003). The present results instead suggest that unitary visual information formulated on the basis of integrative egocentric and allocentric visual cues mediates the specification of movement distance and movement direction. In addition, the fact that the IRE influenced perceptual and reaching tasks similarly counters Goodale and Milner's (1992) assertion of a strict dissociation between the visual processing streams for perceptions and actions.

NOTES

1. In the present work *visually derived actions* refers to those responses in which visual input (i.e., limb and target vision) is available to the performer at the time of response planning (i.e., closed-loop or open-loop responses). As has been shown in a number of recent studies (e.g., Binsted & Heath, 2004; Heath, 2005; Heath, Westwood, & Binsted, 2004), it is important to note that the control parameters of visually derived actions are much different from those associated with memory-guided counterparts (i.e., movements initiated after a period of visual delay).

2. We refer to the target locations associated with the AP-IRE configuration as *far*, *middle*, and *near*.

3. According to the real-time component of the perception–action model, the visuomotor system requires visual information from the reaching environment at the time of response cuing to parameterize a metrical reaching and grasping response (Westwood & Goodale, 2003). Hence, *real-time control* should not be confused with *online control*, in which the visuomotor system uses response-produced visual feedback to modify an ongoing reaching trajectory (e.g., Heath, 2005).

4. Bridgeman et al. (2000; Bridgeman & Huemer, 1998; Bridgeman et al., 1997; Dassonville et al., 2004) did not report the movement times of their "immediate jabbing movements." (Dassonville et al., p. 614). We are therefore unable to speculate whether temporal demands associated with a reaching task influence visuomotor susceptibility to the IRE. However, it is important to note that researchers who used other pictorial illusions (i.e., Brentano illusion) reported that movement speed does not influence visuomotor sensitivity to allocentric visual cues (e.g., de Grave et al., 2004b).

5. Coello et al. (2003) presented the IRE for 400 ms. Because average reaction times in that study were greater than 500 ms, visual input from the IRE was not consistently available to participants throughout response planning.

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