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## Perception-action and the Müller-Lyer illusion: amplitude or endpoint bias?

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**Abstract** Over the past decade there has been a great deal of controversy regarding the relative impact of visual illusions on cognitive judgments and the control of goal-directed action. We report the results of two experiments indicating that perceptual biases associated with the Müller-Lyer illusion involve a misjudgment of amplitude/extent while aiming biases involve error in the specification of a movement endpoint. This dissociation of perception and action is consistent with some aspects of Milner and Goodale's two visual system model, but not others.

**Keywords** Müller-Lyer · Illusion · Perception-action · Dorsal-ventral

### Introduction

The control of goal-directed movement requires perception. One might assume then that the perceptions which we have of our environment (either veridical or illusory) are the same ones used to control action. Milner and Goodale (1995), however, postulate a functional distinction between visual perception and the visual control of

action. Specifically, they suggest that goal-directed movements depend on a separate perception from the one represented by conscious awareness. Here we report two experiments that were conducted to examine this distinction in the context of the visual constraints on the visual perception of amplitude and the control of manual aiming.

The distinction between conscious perception and the visual control of action is based largely on the particular neural pathways, the ventral and the dorsal streams, subserving each. The ventral stream, which projects from the primary visual cortex to the inferior temporal areas of the brain, is thought to be important for language- and memory-based perception. This stream would be responsible for the verbal perceptual reports and button responses described in most perception research. The dorsal stream, on the other hand, projects from the primary visual cortex to the superior parietal regions and is thought to be important for body-referent perceptions that involve movement. This stream would be responsible for the visual control of goal-directed actions. A dissociation of these two functional systems is evident in individuals with a lesion to one or the other visual pathway (Carey et al. 1996; Milner and Goodale 1995).

Evidence for two visual systems is also provided by the perceptual and manual responses that intact participants make to common visual illusions of size. One such illusion is the Ebbinghaus illusion in which a circle is surrounded by a ring of circles. As the circles in the outer ring become larger, the circle in the center is commonly perceived to be smaller, and vice versa. Aglioti et al. (1995), however, report that this illusory effect occurs only in perceptual judgments, not in the control of action; that is, participants scale their finger grip to the *actual* size of the center circle when reaching to pick it up. It has been suggested that the ventral stream codes visual information allocentrically; thus the perceived size of a circle (e.g., Ebbinghaus illusion) is affected by the visual context in which it appears. Motor behaviors associated with dorsal stream function require body-scaled coding of visual space (i.e., egocentric coding) and thus are not susceptible to the influence of visual context.

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Although Milner and Goodale's (1995) perception-action dichotomy has provided a useful framework for understanding a large body of clinical and experimental work (for a review see Norman 2002), not all of the recent research is consistent with the notion that the action system is immune to the influence of visual illusions. Some studies have reported significant effects of the Ebbinghaus illusion on grip aperture that were of the same magnitude as the effects on perceptual reports (Franz et al. 2000; Pavani et al. 1999). Other studies using the Müller-Lyer (M-L) illusion indicate that both eye (Binsted and Elliott 1999a, 1999b; Binsted et al. 2001) and hand (Elliott and Lee 1995; Meegan et al. 2004) movements are biased by the inward-pointing ( $\leftarrow$ ), "wings-in") and outward-pointing ( $\rightarrow$ ), "wings-out") wings.<sup>1</sup> Moreover, the absolute impact of the M-L wings on manual aiming actually appears to increase as an aiming movement toward the vertex of an M-L configuration unfolds (Meegan et al. 2004). This later finding is at odds with Glover and Dixon's (2001) suggestion that movement planning, but not the processes associated with on-line control, is susceptible to the influence of visual illusions. Overall the results of these studies using variations of the M-L illusion are consistent with other findings that indicate aiming movements are influenced by the visual background against which the movements are made (e.g., Brenner and Smeets 1996; Proteau and Masson 1997). They also indicate that participants may code space quite differently depending on the specific contextual information available for limb control (see Post and Welch 1996).

Elliott and Meegan (2004) suggest that, although it makes good sense to prepare and execute movements in a body-referenced framework, it is often important for the control system to be aware of visual context for on-line control.<sup>2</sup> Thus at least in some situations motor performance is influenced by the visual environment that surrounds a target object. With respect to Milner and Goodale's "two visual system hypothesis," this does not necessarily indicate that perception and action are subserved by the same functional system. Rather, it is possible that illusory biases affecting perception and action sometimes occur for different reasons. For example, perceptual biases associated with the M-L illusion may occur because the participant misperceives the extent of the line (Mack et al. 1985). The preparation of an aiming movement, however, usually involves specifying a particular end position (Feldman 1966; Laabs 1973) or posture (Rosenbaum et al. 1995) rather than organizing a movement of a specific distance. Biases in the perception

<sup>1</sup> Binsted and colleagues (Binsted and Elliott 1999a; Binsted et al. 2001) demonstrated that both eye and open-loop hand movements are biased by M-L configurations in which tails were present at only the target end of the figure. It appears that when visual information about the position of the hand is not available during movement execution, extraretinal information about the position and movement of the eyes contributes to manual aiming bias.

<sup>2</sup> Catching a moving object, such as a ball, depends partly on our ability to perceive the expansion of the ball's texture elements relative to the elements in the visual background and to regulate a hand movement accordingly (Elliott and Meegan 2004).

of end position alone then should selectively influence aiming movements.

Two experiments were conducted to examine the perceptual and motor biases associated with variations of the standard M-L configurations. The traditional M-L figures ( $\leftarrow$ ), ( $\rightarrow$ ) were used to induce both an amplitude and a positional bias, while wings-left ( $\rightarrow$ ) and wings-right figures ( $\leftarrow$ ) were used to induce a positional bias (Judd 1898). It was expected that both perceptual judgments and manual aiming would be influenced by the context provided by the wings, but that the perceptual illusion would reflect a misperception of object length, while aiming would reflect a misjudgment of target position. For aiming, we expected endpoint biases to reflect only the wing configuration at the target end of the figure (see Binsted and Elliott 1999a; Binsted et al. 2001). This is in contrast to the cognitive misjudgments of position associated with the Judd (1898) experiments in which both ends of the figure have an equal contribution to the illusion. Thus any misperception of position associated with the Judd configuration would be expected to balance each other out leading to an accurate judgment of extent. We expected this to lead to a dissociation between perception and action. However, in this situation the predicted dissociation is not strictly due to the difference between allocentric (ventral) and egocentric (dorsal) coding (cf. Milner and Goodale 1995; see Tremblay and Elliott 2003), but rather a misjudgment of amplitude (perception) vs. position (aiming).

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## Experiment 1: perception

### Method

#### *Participants*

This experiment included 14 right-handed students from McMaster University (8 men, 6 women; mean age 20.0  $\pm$  1.6 years, range 19–24). All participants had normal, or corrected to normal, vision. The study was conducted in accordance with the ethical guidelines of McMaster University and the Declaration of Helsinki (1964). Participants gave informed consent prior to the experiment and received \$5 as compensation for their time.

#### *Apparatus and task*

Participants sat in front of a table on which various M-L figures would be presented. One of five different target images (Fig. 1) was projected onto a piece of black Bristol board by an Epso PowerLite 50C projector mounted 100 cm above the table. The images had horizontal shaft lengths of 25 or 35 cm and wing lengths of 5.8 or 8.3 cm, respectively. The angle between the wing and the horizontal was always 45°. Following each target image a comparison image was projected onto the same surface. There were five possible comparison lines for each of the

25-cm and 35-cm images. The comparison lines were plain straight lines that were either (a) the same length as the shaft of the image (25 or 35 cm), (b) 20% longer or shorter (30 and 20 cm, or 42 and 28 cm), (c) 10% longer or shorter (27.5 and 22.5 cm, or 38.5 and 31.5 cm). Participants used a standard two-button mouse to make a forced choice as to whether the comparison images appeared longer or shorter than the target image. Participants held the mouse with their right hand 10 cm below the left vertex of the image. E-Prime, version 1.0, recorded participants' responses as well as their reaction times. Reaction time was defined as the time elapsed from the onset of the comparator line until the left (shorter) or right (longer) mouse button was depressed.

### Procedure

Participants performed 200 trials (2 delay×5 image type×5 comparison line×2 length×2 trials) in one 30-min session, taking a break every 50 trials. Each trial began with a "ready" screen, at which time participants were asked to ensure that their mouse was positioned in the designated area. One of ten possible images (5 type×2 length) was then presented for 1 s, followed by either a 0- or 3-s delay period. Participants wore liquid crystal occlusion goggles that closed for the duration of the 3-s delay. Following the delay the goggles opened and one of the five comparison lines was presented. Participants were instructed to respond as quickly as possible by pressing the right mouse button if they thought the comparison line was longer than the shaft of the image they had seen previously. Conversely, if they believed the comparison line was shorter than the prior image, the participants were instructed to press the left mouse button as quickly as possible. Participants were also instructed to inform the experimenter if they pressed the wrong response button so that the appropriate correction could be made.

### Perceptual results and discussion

The number of "longer" responses were summed over target length (i.e., the 25 and 35 cm target figures) and delay (0, 3000 ms) of which an initial analysis indicated had no influence on the perceptual judgments. Figure 2 plots the percentage of longer responses as a function of image type and comparison line. When summed over length and delay, there are eight possible longer responses for each of 14 participants (i.e., 100%=112 longer decisions, 50% or chance=56 longer decisions). As is apparent in Fig. 2, regardless of the target configuration, participants were seldom incorrect when the comparator was 20% shorter or longer than the target figure. However,

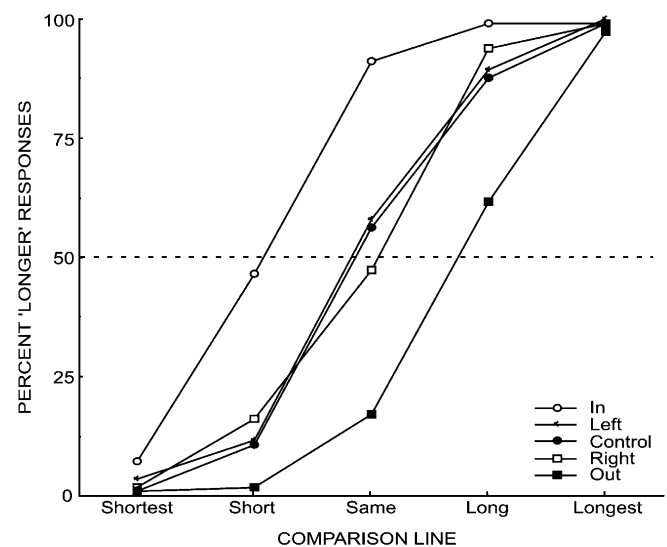


**Fig. 1** The five types of images used in the present experiment

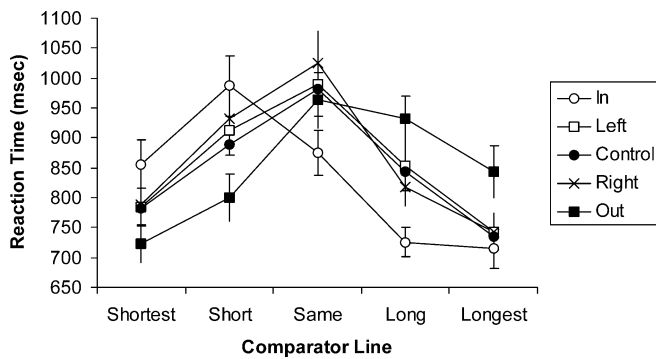
an effect of the illusion was evident when the difference was only 10%. The most telling results are associated with a comparator that was the same length as the target figure. Here a one-factor repeated-measures analysis of variance involving image type conducted on the mean percentage per participant indicated that wings-in values were significantly higher, and the wings-out values were significantly lower than the wings-right, wings-left and control figures ( $F_{(4,52)}=29.76, P\leq.0001$ ; Tukey's "honestly significantly different" test, HSD,  $P\leq.05$ ). The three intermediate figures were not different from either each other nor from a theoretical value of 50% (i.e., chance) (critical value=19.5%). We were not able to conduct similar analyses at other levels of comparator because of homogeneity of variance and normality problems associated with floor and ceiling effects.

The mean reaction time data were analyzed using a 2 delay×5 image type×5 comparison line×2 length repeated-measures analysis of variance. This analysis revealed only a main effect for comparator ( $F_{(4,52)}=35.58, P\leq.0001$ ) and an image by comparator interaction ( $F_{(16,208)}=7.16, P\leq.0001$ ). Participants took more time to make their decisions when the comparator appeared to be the same size as the target image. For the wings-in target image the decision time was longer when the comparator was 10% shorter than when it was the same size (Tukey's HSD,  $P\leq.05$ ; see Fig. 3). For the wings-out target image the decision time was equally slow for the same and the 10% longer comparator conditions ( $P\geq.05$ ). Thus it appears that perceived figure amplitude affects decision time at least as much as real figure amplitude.

In summary, both the reaction time data and the perceptual judgments were consistent with previous findings that indicate wings-in M-L figures appear shorter than they really are while wings-out figures appear longer (Judd 1905). The misperception of shaft extent occurred even though participants were required to make their perceptual decisions very rapidly (i.e., less than 1 s) thus



**Fig. 2** Mean number of "longer" responses as a function of image type and comparison line



**Fig. 3** Mean reaction time and standard error bars as a function of image type and comparator line

reducing the memory requirements associated with the decision-making process. For the wings-left and wings-right configurations no extent bias was evident. Thus any misperception induced by one end of the figure seemed to be balanced by the other end of the figure leaving the overall perception of shaft length unaffected.

## Experiment 2: action

### Method

#### Participants

This experiment included 14 right-handed students from McMaster University (7 men, 7 women; mean age  $22.2 \pm 1.7$  years, range 20–25). All participants had normal, or corrected to normal, vision. The study was conducted in accordance with the ethical guidelines of McMaster University and the Declaration of Helsinki (1964). Participants gave informed consent prior to the experiment and received \$5 as compensation for their time. None of the participants had been involved in experiment 1.

#### Apparatus and task

The same five target images were used in this protocol as in the perceptual protocol. However, there were no comparator images. In the motor protocol participants made aiming movements with a 13.5 cm metal stylus from the left vertex of each M-L configuration to the right vertex. Consistent with previous work from our laboratory (Meegan et al. 2004), participants were instructed to hold the stylus so as not to block vision of the left end of the M-L configuration. A single infrared light emitting diode was placed at the end of the stylus. An Optotrak-3020 recorded participants' movements at 200 Hz for 2.5 s after a beep prompted participants to begin their movement. A pair of liquid crystal goggles was used to occlude vision during the delay period, and the aiming movement. E-Prime, version 1.0, integrated the presentation of the stimuli, as well as the delay period, and through the parallel port,

controlled the liquid crystal goggles, and the initiation of the Optotrak.

#### Procedure

Prior to each trial participants were required to position the end of the stylus on a small home position in the same position as the left vertex of the to-be-presented figures. Following a ready signal, one of ten possible images (5 type, 2 length) was displayed for 1 s, followed by either a 0- or 3-s delay. After the delay a beep prompted the participant to make an aiming movement with the stylus to where he/she believed the right vertex of the image had been located. Vision was occluded during the delay period, as well as during the aiming movement, and returned 2.5 s after the beep had cued the participant to move. The return of vision prompted the participant to return the stylus to the start position. The 10 different combinations of image type and delay period were presented in a random order for a total of 200 trials. Participants were instructed to move as quickly as possible, but to try to hit the point where the three lines intersected (i.e., the vertex). A short break was taken after every 50 trials.

#### Data reduction

All of the performance and kinematic variables were derived from Optotrak data using custom-made software. Optotrak displacement data in the primary direction of the movement were initially filtered using a dual-pass Butterworth filter with a cutoff frequency of 12 Hz. The filtered displacement data were then differentiated to obtain velocity. Movement start and finish were identified as the sample at which movement velocity rose above or fell below 30 mm/s and remained there for 70 ms (14 samples). Movement time was calculated by multiplying the difference between the start and end frames by 5 ms (i.e., 200 Hz sampling rate). The custom software (Chua and Elliott 1993) was used to identify peak velocity and to determine the time spent before and after peak velocity.

Movement endpoint location along with the known location of the figure vertex was used to calculate constant and variable target-aiming error. Constant error is the mean algebraic error in the primary direction of the movement (X-axis). It provides information about a performer's tendency to undershoot (i.e., negative error) or overshoot (i.e., positive error) the target. Variable error is the standard deviation of the performer's endpoints. It provides information about the within-participant consistency of the aiming movements (Schmidt and Lee 1999).

#### Motor results

With respect to illusion-induced bias, our most important dependent variable was constant error. A 2 delay $\times$ 5 image $\times$ 2 length repeated-measures analysis of variance

conducted on participant's constant error scores revealed main effects for delay ( $F_{(1,13)}=13.95$ ,  $P\leq.01$ ), image ( $F_{(4,52)}=32.23$ ,  $P\leq.0001$ ), and length ( $F_{(1,13)}=6.13$ ,  $P\leq.05$ ) and no interactions. Overall, participants undershot the target position to a greater extent in the 3-s delay condition (-14.5 mm) than they did in the 0 s delay situation (-6.5 mm). They also undershot the 35 cm target distance (-14 mm) more than the 25 cm target distance (-7 mm). Both of these results are consistent with previous findings. Specifically, participants tend to undershoot target positions when there is a memory requirement associated with determining the target's position (i.e., the 3-s delay situation; Elliott and Madalena 1987). We have suggested elsewhere that undershooting in general reflects a play-it-safe strategy associated with safety and minimizing both the temporal and energy requirements of an aiming movement (Elliott et al. 2004). The greater undershooting for 35 cm movements compared to 25 cm movements is a typical range effect (Pepper and Herman 1970). Range effects are assumed to be the result of either perceptual or motor averaging, in this case between the two movement amplitudes. Of importance in this study is that this range effect was independent of target configuration (i.e., length by image interaction  $F<1.0$ ). This indicates that range effects and manual aiming bias due to target configuration are subserved by different information processing systems (see Sternberg's 1969 additive factor logic).

In terms of our hypothesis, our most important finding was the main effect for Image that is depicted in Fig. 4. Post hoc analysis of this effect (Tukey's HSD,  $P\leq.05$ ) revealed the participants made longer movements in the wings-out condition and the wings-right condition than they did in the wings-in and the wings-left condition. However, the wings-out and wings-right conditions, and the wings-in and the wings-left condition were not reliably different from each other. The control condition was intermediate and significantly different for all other conditions except the wings-right condition. From the overall pattern of the Image results, it would appear that the wings associated with the actual target have more impact on aiming bias than the perceived length of the figure. This finding contrasts with the results involving the perceptual protocol. Consistent with our hypothesis, it is the position of the target endpoint and not the perceived length of figure that drives the aiming movement.<sup>3</sup>

The variable error analysis also produced some interesting results. Specifically, there was a main effect for delay ( $F_{(1,13)}=61.34$ ,  $P\leq.0001$ ) and a delay by image interaction ( $F_{(4,52)}=3.23$ ,  $P\leq.05$ ). Overall, participants were more variable in their aiming if they were required to sit in the dark for 3 s (19 mm) as opposed to aiming

<sup>3</sup>One could argue that always starting the movement at the left vertex of a configuration would lead participants to adopt an end position strategy (i.e., simply ignore the left vertex). However, it was also the case that target lines and comparison lines always originated at the left vertex in the perceptual protocol. Thus, perceptual judgments could have been made based only on the endpoint of the target and comparison shafts. This was not the case.

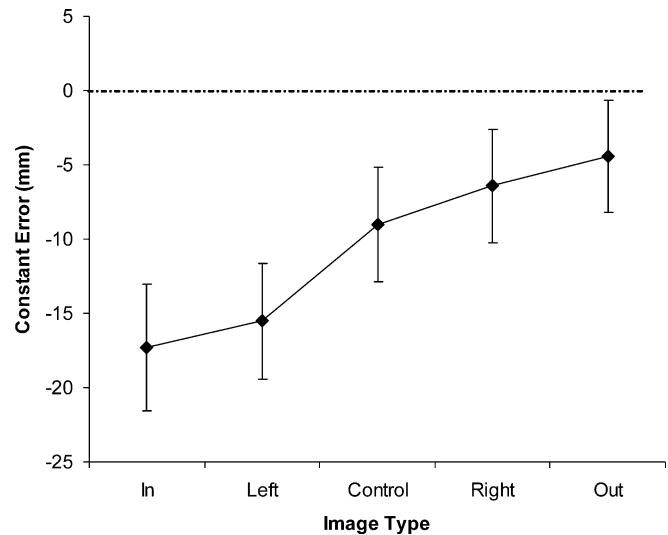


Fig. 4 Mean constant error and standard error bars as a function of image type

immediately after visual occlusion (14.5 mm). Elliott and Madalena (1987) have suggested that the influence of delay on movement variability is associated with decay in the visual representation of target position over the no vision delay interval. This pattern of increased error is also consistent with the idea that the performer becomes more dependent on ventral stream function for limb control as the memory requirements associated with limb control increase (Milner and Goodale 1995; Westwood and Goodale 2003). The delay by image interaction is depicted in Fig. 5. The increased endpoint variability associated with delay was greater for the illusory configurations than for the control figure. Perhaps an X provides a more salient target to remember that half an X (< or >).

A 2 delay $\times$ 5 image type $\times$ 2 length repeated-measures analysis of variance conducted on the mean reactions times revealed only a main effect for delay ( $F_{(1,13)}=9.11$ ,  $P\leq.01$ ). Participants were slower to respond in the 0 delay situation (375 ms) than in the 3-s delay condition (347 ms). This difference may be due to the fact that in the 3-s condition participants had more real time between target presentation and the signal to prepare their aiming movements (e.g., 1 s in the 0-s delay condition and 4 s in

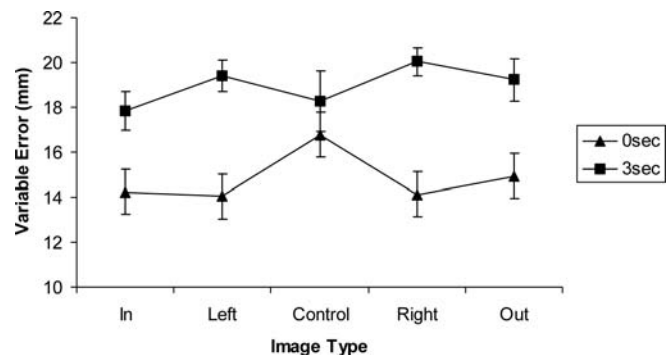


Fig. 5 Mean variable error and standard error bars as a function of image type and delay period

the 3-s delay condition). In any case, limb reaction times were much shorter than the times required to make a decision in the perceptual protocol.

A similar analysis conducted on movement time yielded main effects for all three factors: delay ( $F_{(1,13)}=9.97$ ,  $P\leq.01$ ), image ( $F_{(4,52)}=2.69$ ,  $P\leq.05$ ), and length ( $F_{(1,13)}=38.35$ ,  $P\leq.0001$ ). Not surprisingly, participants required more time to complete long movements (411 ms) than short movements (379 ms). They also completed their movements more quickly in the 0-s delay situation (389 ms) and in the 3-s delay condition (401 ms). Post hoc analysis (Tukey's HSD,  $P\leq.05$ ) revealed that participants completed their movements more quickly in the wings-in condition (393 ms) and the wings-left condition (392 ms) than they did in the wings-out (396 ms), control (397 ms) and wings-right (398 ms) conditions.

As one might expect from the movement time results, kinematic analyses (see Table 1) revealed that participants achieved higher peak velocities for 35 cm movements than

25 cm movements ( $F_{(1,13)}=141.11$ ,  $P\leq.0001$ ). For longer movements they also took more time to achieve peak velocity ( $F_{(1,13)}=63.34$ ,  $P\leq.0001$ ) and spent more time after peak velocity ( $F_{(1,13)}=18.48$ ,  $P\leq.001$ ). These are typical index of difficulty effects (for a recent review see Elliott et al. 2001). In terms of delay, participants reached greater peak velocities earlier in the movement in the 0-s delay situation than they did in the 3-s delay condition: peak velocity ( $F_{(1,13)}=55.32$ ,  $P\leq.0001$ ) and time to peak velocity ( $F_{(1,13)}=7.66$ ,  $P\leq.05$ ). They also spent significantly less time after peak velocity ( $F_{(1,13)}=8.54$ ,  $P\leq.05$ ). Elliott (1992) has suggested that in a no-vision 0-s situation participants attempt to complete their movements quickly so that their limb reaches the target area before a short-lived visual representation of the target position has had a chance to decay (see also Elliott and Madalena 1987).

Of greater interest with respect to our hypothesis are the kinematic results associated with Image. Specifically,

**Table 1** Mean of peak velocity, time to peak velocity, time after peak velocity, and movement time as a function of delay, image, and length

	Peak velocity (mm/s)	Time to peak velocity (ms)	Time after peak velocity (ms)	Movement time (ms)
0-s delay				
Wings-in				
250 mm	1221±271	184±38	189±52	373±87
350 mm	1666±407	192±37	209±69	401±105
Wings-left				
250 mm	1245±265	182±37	189±53	371±87
350 mm	1625±368	195±39	209±64	404±100
Control				
250 mm	1268±281	183±37	193±60	376±94
350 mm	1653±367	198±42	208±67	407±106
Wings- right				
250 mm	1278±275	183±38	192±60	375±95
350 mm	1688±383	195±39	214±65	409±101
Wings-out				
250 mm	1282±271	182±37	194±60	376±94
350 mm	1683±389	197±38	210±70	406±105
3-s delay				
Wings-in				
250 mm	1129±239	184±32	198±47	382±74
350 mm	1553±388	201±41	214±67	415±105
Wings-left				
250 mm	1167±252	179±31	204±56	382±85
350 mm	1541±363	201±37	210±70	411±105
Control				
250 mm	1162±249	188±44	200±49	388±90
350 mm	1565±381	201±38	217±70	419±105
Wings- right				
250 mm	1195±256	183±34	200±53	384±85
350 mm	1597±406	205±49	219±73	424±119
Wings-out				
250 mm	1189±270	187±33	197±61	384±90
350 mm	1591±372	203±45	215±66	418±108

participants achieved higher peak velocities in the wings-out and the wings-right situations than they did for wings-in and wings-left situations ( $F_{(4,52)}=8.85$ ,  $P\leq.0001$ ; Tukey's HSD,  $P\leq.05$ ). As evidenced in the overall length effect, higher peak velocities are typically associated with longer movements. The longer movement times in the wings-out and wings-right situation appear to be due to a combined influence of the time spent before and after peak velocity (both  $P\geq.05$ ).

In summary, aiming movements were affected more by the configuration at the target end of the figure than the nontarget end of the figure. This was true not only for constant error but also for movement time and the actual characteristics of the movement trajectory. Specifically, when participants were biased by the target configuration to make longer or shorter movements, the kinematic characteristics of the trajectories were consistent with movements of greater and lesser amplitude, respectively. The overall pattern of results indicates that participants prepare movements to a particular position in space rather than movements of a specific amplitude. Because visual information about the position of the target and the hand was not available during movement execution, there was little opportunity for effective on-line control. In a full vision situation the opportunity for visual on-line control has been shown to reduce manual aiming bias to near zero (Binsted et al. 1999a, 1999b; see also Elliott and Lee 1995).

Although the main purpose of this study was to examine the dissociation between perceptual judgments of extent and processes that require the motor system to code for end position, this study also provided us with an opportunity to examine Glover and Dixon's (2001) suggestion that movement planning processes are susceptible to the influence of visual illusions while on-line control processes are not. Following Meegan et al. (2004), we examined the amplitude of our aiming movements at peak acceleration, peak velocity, peak deceleration, and the end of the movement. Using the control figure as a standard, we calculated amplitude difference scores for each of the other four figures. These difference scores are plotted in Fig. 6. A 4 kinematic marker $\times$ 2 delay $\times$ 4 image type $\times$ 2 length repeated-measures analysis of variance conducted on these scores revealed both a main effect for image ( $F_{(3,39)}=23.11$ ,  $P\leq.001$ ) and an image type by kinematic marker interaction ( $F_{(9,117)}=14.98$ ,  $P\leq.001$ ). Post hoc analysis (Tukey's HSD,  $P\leq.05$ ) of the interaction revealed that the wings-right and wings-out figures were significantly different than the wings-left and wings-in figures at all kinematic markers except peak acceleration where the four figures did not differ. This increase in illusion-induced bias as the movement unfolds is exactly opposite to what Glover and Dixon's planning-control hypothesis predicts. Specifically, according to their model, on-line control processes should reduce and perhaps eliminate planning induced bias over the course of movement execution.

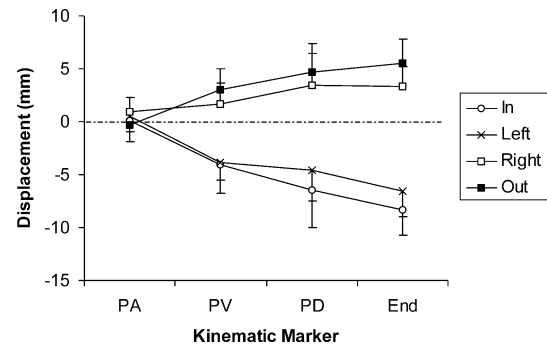


Fig. 6 Mean displacement and standard error bars as a function of image type and kinematic marker (*PA* peak acceleration, *PV* peak velocity, *PD* peak deceleration, *END* end of movement)

## General discussion

Although visual cognitive systems appear to be susceptible to perceptual biases induced by visual illusions, there is mixed evidence as to the influence of illusions on grasping and aiming movements (e.g., van Donkelaar 1999; Elliott and Lee 1995; Franz 2001; Gentilucci et al. 1996). The premise of this study was that goal-directed movements may be affected by a different set of contextual variables than cognitive judgments. Specifically, we hypothesized that perceptual illusion and manual aiming biases associated with M-L figures (i.e., Meegan et al. 2004) sometimes occur for two different reasons.

In this context, Mack et al. (1985) published a series of influential studies that indicate the M-L illusion is primarily due to a misperception of the length of the figure shaft and not a misjudgment of position (see also Gillam and Chamber 1985). However, in the motor domain the preponderance of behavioral and physiological evidence suggests that aiming movements are organized with respect to a specific spatial goal that involves the coding of both direction and position (for a review see Burnod et al. 1999). In the context of this experiment in which direction does not vary, target position takes on greater importance than the distance over which the limb must travel (Laabs 1973). This type of movement organization makes sense from a representation point of view because the same end location can be achieved from a variety of starting locations, while movement preparation based on extent or amplitude must take into consideration both the start and end positions of the limb. Within this framework it is unlikely that perceptual-cognitive judgments and the visual control of action depend on the same visual information even if performance biases are similar for some visual illusions (e.g., the M-L illusion). Certainly in terms of hardware there is evidence that the visual control of movement involves a complex parietofrontal network (Salinas and Abbott 1995), while cognitive judgments, such as object recognition, entail greater temporal involvement (Tanaka 1993).

Although our perceptual metric did not allow us to directly compare the perceptual decision making and manual aiming with traditional M-L configurations, we were able to demonstrate that both types of performance

were biased in the expected direction. That is, compared to the control figure, wings-in figures were judged shorter and wings-out figures were judged longer. As well, the two configurations induced shorter and longer movements, respectively. However, the wings-left and the wings-right configurations had an impact on manual aiming but not on the perceptual judgments that participants made. This suggests that the actual target endpoints induce a misperception of target position. Presumably it was this misperception of position that contributed to aiming biases in the traditional M-L figures as well. Thus in this particular context we have a dissociation between perception and action that may very well reflect the separate contributions of the ventral and dorsal streams to visual processing. The dissociation, however, does not appear to reflect the difference between allocentric and egocentric spatial representation.<sup>4</sup>

Our extent vs. position dissociation is only relevant to the M-L illusion. However, for most perceptual-motor tasks there are multiple sources of information that have the potential to contribute to performance. Although visual context can lead to movement error under contrived conditions, such as the conditions used in this study, there are many situations in which the motor control system needs to know about the environmental context in order to interact with a particular target rapidly and safely (e.g., grasping food from a thorny bush). Thus it makes sense that movement planning and on-line control systems have evolved to provide maximal flexibility.

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<sup>4</sup>Tremblay and Elliott (2003) have shown that cognitive vs. motor decision-making influences the magnitude of vestibular bias on judgments of the visual straight-ahead in the absence of any visual context (i.e., a completely dark room).