Mirror image arm used in monocular, binocular, and blindfolded pointing

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Abstract Observers were instructed to point with their right arm to a mirror image of their left shoulder. Instead of pointing to the target with their real arm, they occluded the target with their mirror-imaged finger, and their real finger pointed off to the left side of the target, facts that came as a surprise to them in debriefing. The occlusion by a mirror image finger was not done to avoid double images, since it occurred in monocular conditions. That it is due to planning before pointing can be inferred from the fact that it occurred in blindfolded conditions.

Keywords Pointing · Mirror

At times, we control intermediary objects rather than act directly on our targets. In tele-robotics, we control devices that lift, cut, weld, and so forth. If the device and its tools are in front of the controller, the tools (pincers, scalpels, scissors, and the like) are not occluded by parts of the tele-robot. However, Sutter and Müsseler (2010, p. 1767) write, “When taking the viewpoint of a robotic avatar [a tele-robot] . . . the actor has to account for the perspective. . . . E.g. in a face-to-face perspective with an avatar, moving the left hand means from the viewpoint of the observer the avatar moves its right hand.” In contrast, motion of the actor’s right arm

produces motion on the right side of a mirror image from the actor’s point of view. This would be motion of a left arm if the mirror image was changed to a real person. We report here that we asked observers to point at a mirror image target and, strikingly, actors used mirror image limbs to fulfill the instructions. Stated precisely, the mirror image fingertip, not the real finger, was on the line from the actor’s viewpoint to the mirror image target. This occurred in monocular viewing as well as binocular conditions. Furthermore, observers were unaware that they had used a mirror image fingertip. Of special interest, we report that the mirror-imaged fingertip was aligned with the target even if the pointing was undertaken blindfolded after the target had been viewed.

In brief, facing a full-length mirror, observers saw their left shoulder, and their mirror-imaged arms hung straight down. They were asked to point to the left shoulder with their right arm (arm straight and finger outstretched) in one swift motion, (i.e., ballistically). Figure 1 is a photograph of a woman undertaking the pointing task in a pilot study. The person was naïve about the ideas being tested. In the picture, her outstretched arm is pointing considerably to the left of the shoulder target. What is aligned with the target, and partially occluding it, is the mirror image of the woman’s finger. Of note, shown the picture, in debriefing, the woman was surprised by the arm pose and the occlusion of the target by her mirror image finger.

Figure 2 shows (from above, as azimuths) three ways to point. For person A, the real arm and outstretched finger are aligned with the mirror-imaged shoulder, aimed like a *spear*. For person B, the *real fingertip* occludes the mirror-imaged shoulder. For person C, a *mirror-imaged fingertip* is on the line from the viewing eye to the target, as in Fig. 1. Azimuth is horizontal deviation from a baseline (Fig. 3), and measuring azimuth as the acute angle formed by the observer’s real arm and the plane through the observer’s shoulders, azimuths of the arm are least for the *mirror-imaged fingertip* case and greatest for the *arm-as-spear* case.

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Fig. 1 Woman pointing with the right arm to a mirror image of her left shoulder. The mirror image finger occludes the shoulder. The real arm points to the left

Pointing strategies of persons A and B have been studied. For example, Wnuczko and Kennedy (2011) tested onlookers judging other people pointing at real targets and participants actually pointing at targets selected by the experimenter. Onlookers judged the target to be in the direction of an imaginary line extending from the pointing person's arm and finger. That is, they took the arm to be acting like a spear aimed at the target. However, instructed to point, people reliably set their fingertip close to the line from the observer's eye to the target. The fingertip partially occluded the target in the observer's visual field. In effect, to point to a ship on the horizon, the pointing arm is elevated above horizontal. To an onlooker, it appears that the person is aiming above the horizon into the sky.

Besides spears and real-fingertip occlusion, if the observer is standing in front of a mirror, there is a third option, albeit a remarkable one. Observers can align their mirror image fingertip with the mirror image target as in Fig. 2, person C. At first thought, this may seem counterintuitive.

Fig. 2 Pointing options shown from above. The lower figure is the person, and the upper figure is the mirror image. Person A's real finger and arm align like a spear with the target. Person B's real fingertip is aligned with the eye and the target. Person C's mirror-imaged finger is aligned with the eye and the target

Fig. 3 Dimensions of the participants: the cyclopean eye, the right shoulder location, and right arm length

(It certainly did to us initially.) However, there are reasons the mirror image might be used in this fashion, given that human observers seemingly effortlessly incorporate remote information to perceive themselves in and to interact with the environment. Muscle, tendon, and joint somesthesia, kinesthesia, and haptics are not the sole source of information for self-perception. In a highly compelling fashion, optic flow can indicate that the body is moving forward or rotating (Gibson, 1979). Also, vision allows self-perception of most of the body, and mirrors substantially provide the same kind of optic information about one's body that is gained in direct inspection. Nevertheless, people make mistakes when asked what can be seen in a mirror (Croucher, Bertamini, & Hecht, 2002), when they predict the location of the object reflected (Hecht, Bertamini, & Gamer, 2005), in judging the size of the image on the mirror (Lawson, Bertamini, & Liu, 2007) and stating how mirror images move as an object moves (Savardi, Bianchi, & Bertamini, 2010).

However, human observers and likely some other species recognize that it is precisely oneself at the present moment one sees in a mirror (Bertamini & Parks, 2005; Krois, 2011). Actions by the observer are instantly available to view via the mirror, a close timing that can reinforce the significance of optic information for self-perception (Longo & Haggard, 2009). Mirror images are often involved in self-grooming. Sutter and Müsseler (2010) suggested that imitation of someone face to face with us is easier if we act as mirror images of role models than if we try to copy their right-limb actions with our right limb. Furthermore, given instructions to act, such as “lift the right-hand index finger,” the action is facilitated by a picture of a left hand with its index finger raised (Brass, Bekkering, Wohlschlaeger, & Prinz, 2000). This is a mirror image picture.

Sutter and Müsseler (2010), testing displays that influence self-perception and action, offered screen-projected

images showing the hands from directly above. Projections that were based on rotations about an *x*-axis (mirror-images) facilitated action, as compared with images that were rotations about the *y*-axis, and, of interest, mirror images were on a par with images with no rotations. Head-mounted displays showing the observers their own image from the back (as if, paradoxically, they were standing in front of themselves) produce the intriguing result that observers report that they sense themselves as located in front of their own actual location (Lenggenhager, Tadi, Metzinger, & Blanke, 2007). In “rubber-hand” effects (Tsakiris & Haggard, 2005), if a rubber hand is gently stroked as the real hand is being stroked, observers misreport the location of their real hand as the location of the rubber hand. Ramachandran and Rogers-Ramachandran (2000) reported that mirror images of one’s limbs that appear in the place of a phantom limb can dispel pain in the phantom limb. Hence, there are reasons for suspecting that, on occasion, an image can be used in lieu of the observer’s actual body.

Longo and Haggard (2009) suggested that vision of one’s own hand movements, together with a sense of agency over the hand, primes motor responses. Sutter and Müsseler (2010) went further. They contended that priming occurs via intention and does not require an actual action to be undertaken. If the motion is ballistic, the primed relationships govern the motion and the final posture. Visual conditions create the superimposed relations prior to the action. Once vision has imposed key relations, the action can be initiated, and the final posture can be achieved in blindfolded conditions.

Prodding a cooked potato with a fork, we attune to information for the distal state, the softness or hardness of the potato, not the proximal motion and pressures of the fork wielded by the hand (Arzamarski, Isenhowe, Kay, Turvey, & Michaels, 2010). Sutter and Müsseler (2010) argued that the actor attuned to perceptual information for a distal state is sometimes hardly aware of his or her own proximal acts. Use of a mirror in pointing tasks could reveal active conditions in which observers relying on optic information use a distal state as a substitute for their own body.

The use of an imaged pointing limb in Fig. 1 might simply be to minimize double images. A proximal limb pointing at a distal target presents different inputs to the two eyes. The difference in the inputs is reduced if the mirror image of the limb is employed. Being optically further than the real limb, it projects more similar inputs to the two eyes. If reduction of binocular differences is at issue, the effect should not appear in monocular or blindfolded conditions. In opposition to this argument, however, we should point out that the double images would not be present until the final pointing pose is adopted. Hence, they might not influence a ballistic motion toward the final pose, and mirror image use could be evident in monocular, binocular, and blindfolded tests.

In sum, observers pointing may use their right arm to control a mirror image’s left arm and occlude a target mirror-imaged shoulder in monocular, binocular, and blindfolded conditions.

Method

Participants

Sixteen undergraduates from University of Toronto, Scarborough, were tested (mean age = 18.9 years, *SD* = 0.8; all right-handed; 4 men).

Apparatus

Participants stood 3 m in front of a flat, vertical mirror (122 × 243 cm, bottom edge 10 cm above the floor). The participant’s right arm was fastened to a stick in an apparatus bearing a protractor that measured azimuths (Fig. 4). The apparatus is a variation of one used by Wnuczko and Kennedy (2011) to measure arm elevation. The apparatus allowed the outstretched arm to move up and down ($\pm 180^\circ$) and right and left ($\pm 60^\circ$). The side of the frame to which the pointer was attached could rotate in place, via bolts top and bottom, and the azimuth protractor indicated the degree of rotation. Zero azimuth was pointing to the left of the observer, and 90 was orthogonal to the frontal plane through the shoulders. The pointing motion was demonstrated by the experimenter, and then the participants practiced pointing to a target seen directly (i.e., not via the mirror).

Procedure

After practice, participants were placed in the apparatus, in front of the mirror, and were instructed to point to the mirror image of their left shoulder. Participants pointed blindfolded (after looking at the target before each trial), as well as in binocular and monocular conditions, with the order of conditions randomized. In the monocular condition, half of the participants pointed with the left eye open, half with the right eye open. There were ten trials per condition, massed, followed by debriefing.

Measurements of shoulder locations and arm lengths (Fig. 3) enabled the locations of the fingertips at particular azimuths to be calculated. A ruler was placed vertically on the shoulder to measure eye height above the shoulder. To measure the distance from the shoulder plane to the cyclopean eye, the ruler was set horizontally at eye height against a flat form placed on the shoulder, parallel to the median plane. The cyclopean eye was taken to be midway between the eyes.

Fig. 4 Apparatus for measuring the azimuth of a pointing arm. An ellipse beside the azimuth protractor shows an elevation protractor

Results

Response azimuths are measurements of the participants' arms when pointing. These are shown by the three left columns of Fig. 5 (taking the means of each participant's mean, blindfolded, $M = 58.1^\circ$, $SD = 5.6$; binocular, $M = 53.9^\circ$, $SD = 4.9$; monocular, $M = 55.1^\circ$, $SD = 5.3$). Of interest, variability as shown by SD s was low (about 10% of the means) and similar in all conditions, including the blindfolded condition. The columns on the right show the azimuths calculated from the participant's body dimensions (arm like a spear, $M = 86.5^\circ$, $SD = 0.5$; real fingertip aligned, $M = 74.7^\circ$, $SD = 2.0$; and mirror-imaged fingertip aligned, $M = 53.9^\circ$, $SD = 5.8$). In all conditions, the mean azimuth of the responses of most participants differed less from their calculated mirror-imaged fingertip azimuth than from the two alternatives (binomial with three alternatives; blindfolded, 12 of 16 participants, $z = 3.75$, $p = .002$; monocular, 14 of 16 participants, $z = 4.33$, $p = .00002$; binocular, all participants, $p < .00001$). A one-way repeated measures ANOVA shows the pointing conditions to be different, $F(2, 14) = 7.21$, $p = .007$, $\eta^2 = .51$. Paired t -tests reveal blindfolded azimuths to be larger than monocular azimuths, $t(15) = 3.45$, $p = .004$, and binocular azimuths, $t(15) = 3.84$, $p = .002$. There was no difference between monocular and binocular azimuths, $t(15) = 1.71$, $p = .11$.

Discussion

The mean azimuths of the responses were essentially identical to those calculated for mirror-imaged fingertip alignment (notably, binocular mean, 53.9° ; mirror image fingertip aligned, 53.9°) but differ remarkably from those for the like-a-spear and real-fingertip alignment alternatives. Hence, most observers occluded the target with the virtual image of their finger. Since this occurred in monocular and blindfolded conditions, it cannot be that the mirror-imaged finger is chosen to diminish double images of the finger (Khan & Crawford, 2003). Since it occurred in blindfolded conditions, it is likely that the final azimuth is planned before raising the arm. The mean response in blindfolded conditions was 58.1° , different by only 4.2° from mirror-imaged fingertip aligned ($M = 53.9^\circ$) but by 28.4° from like a spear (86.5°) and 18.6° from real-fingertip aligned (74.7°). Hence, although there were differences between blindfolded and eyes-open conditions, the responses in blindfolded conditions indicate mirror image alignment for the majority of blindfolded participants (12 of 16 responded closer to mirror image fingertip alignment than to either of the other options).

In debriefing, all participants were asked to pose with their real arm aligned with the target and also to pose with their mirror-imaged finger occluding the target. They often argued that they had been pointing with their real arm aligned with the target. In poses where the mirror-imaged finger occluded the target, it would sometimes take several attempts to get them to notice that their real arm was pointing off to one side.

Fig. 5 Blindfolded, binocular, and monocular pointing azimuths (means, in degrees, with SE error bars; zero is the plane through the shoulder). On the left, participant response azimuths show how participants pointed. On the right, calculated from body dimensions, azimuths show how participants would have pointed if aligning the arm with the mirror image target, occluding the target with the real fingertip, or occluding the target with the mirror image fingertip. * $p < .05$

In pointing, many means can be used; for example, direction can be shown by a head nod or the motion of a hand. A virtual image can offer optic information about oneself: “My finger is pointing.” The participant may attend to (1) the target and (2) the occluder, “my finger.” That it is “my virtual finger” is treated as irrelevant, and paradoxically, also irrelevant is that the virtual arm in the 3-D image space stretches toward the actor, so the virtual arm and finger are aimed at a region to the left of the virtual shoulder and some distance in front of it. Evidently, select properties allow the image to be “an agent of the self” (Longo & Haggard, 2009). Admittedly, these are not yet well-defined terms. More sure is that the effect is a converse of that in Ramachandran (2009): “A patient with a phantom arm simply watches a student volunteer’s arm being touched. Astonishingly the patient feels the touch in his phantom.” Likewise, it is the converse of that in Ehrsson (2007), who fed images from video cameras showing rods approaching an image of their body to normal observers, who reported being touched. In the present study, rather than a distal touch experienced as proximal, in mirror image use, a proximal limb controls a distal one, which undertakes “me pointing by means of occlusion.”

Before the participant pointed, the mirror-imaged finger was visible in the mirror, optically closer to the target than the real finger, which was hanging down. During pointing, the real arm is below the mirror image arm in the participant’s visual field. That is, the real arm is less elevated, as Fig. 1 shows. It does not occlude the mirror arm or the target shoulder. By itself, merely being optically closer to the target initially does not cause mirror arm use, since in pilot studies, observers pointing to mirror image targets high above their mirror-imaged heads used their real arms to point. In these cases, the final pose had the real pointing finger more elevated than the mirror image and closer optically to the target.

The use of the mirror arm here depends on visual information and, so, is related to visual capture, in which visual information for a false position of a limb overwhelms valid kinaesthetic and tactile information for the limb. However, it occurs here with both real and mirror-imaged limbs in view.

In pilot studies, with and without use of the pointing apparatus, we found that people of many ages (8–75; family, friends, university students, staff, and colleagues) used their virtual arms to point, with mirrors half the length of the one used here and mirrors many meters wide and tall in hallways and in sports facilities, standing a few meters from the mirror or 10 meters distant. Also, when we placed a camera as in Fig. 1 and took photos of the pointing arm and target, pilot volunteers were surprised that their real arm pointed considerably to the left of the mirror. If we positioned their arms as “spears” aligned with the target, or with the real finger occluding the target, the mirror-imaged finger was

above the real arm in the observer’s visual field but did not occlude the target. Nevertheless, pilot study observers described those scenes as strange, awkward, and surprising. One pilot study observer who aligned the real arm with the target like a spear reported practice in target-shooting—a failure-to-occur that may be useful for examining theories of mirror-arm pointing. Although simple and highly replicable, it may be vulnerable to any practice with aiming that makes people aware of options in pointing.

In grooming, we control mirror images of hands—for example, to comb hair or put on creams. This use of real hands as tools, and deployment of hands wielding tools, is guided via the virtual hands, although of course, the real hands do the work. In contrast, in the present study, observers put mirror images to work. The images, not the real hands, occluded the target.

We can offer a suggestion about a possible succession of psychological events, based on observations made in pilot studies with volunteers without apparatus, who sometimes tested ways of pointing. Perhaps most observers entertain two ways of pointing. They may consider bending their right arm in front of them so that the index finger of their right hand would touch their left shoulder. Their mirror-imaged left shoulder would then be touched and pointed to by their mirror-imaged right arm. But, they are aware, this is not pointing with an outstretched arm. They then may envisage an outstretched arm *in the mirror* and how to pose it to occlude the mirror-imaged shoulder. What they envisage requires that they anticipate the real arm at a certain position and prepares them to move their real arm to that pose. We concede that this two-step order of events is highly speculative. It may be that the sequence is rapid, based on well-practiced grooming actions. If it is indeed rapid, it might not require conscious awareness of the sequence. Alternatively, observers may take only one mental step. Their goal may be to point by means of occlusion, occluding the shoulder by controlling a limb that is near in direction. In sum, a mirror image was used for pointing; we have offered suggestions about the significance and production of this result.

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References

- Arzamarski, R., Isenhower, R., Kay, B., Turvey, M. T., & Michaels, C. F. (2010). Effects of intention and learning on attention to information in dynamic touch. *Attention, Perception & Psychophysics*, 78, 721–735. doi:10.3758/APP.72.3.721
- Bertamini, M., & Parks, T. E. (2005). On what people know about images on mirrors. *Cognition*, 98, 85–104. doi:10.1016/j.cognition.2004.11.02

- Brass, M., Bekkering, H., Wohlschlaeger, A., & Prinz, W. (2000). Compatibility between observed and executed finger movements: Comparing symbolic, spatial, and imitative cues. *Brain and Cognition*, 44, 124–143. doi:[org/10.1006/brcg.2000.1225](https://doi.org/10.1006/brcg.2000.1225)
- Croucher, C. J., Bertamini, M., & Hecht, H. (2002). Naive optics: Understanding the geometry of mirror reflections. *Journal of Experimental Psychology: Human Perception and Performance*, 28, 546–562. doi:[10.1037/0096-1523.28.3.546](https://doi.org/10.1037/0096-1523.28.3.546)
- Ehrsson, H. H. (2007). The experimental induction of out-of-body experiences. *Science*, 317(5841), 1048. doi:[10.1126/science.1142175](https://doi.org/10.1126/science.1142175)
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton-Mifflin.
- Hecht, H., Bertamini, M., & Gamer, M. (2005). Naive optics: Acting upon mirror reflections. *Journal of Experimental Psychology: Human Perception and Performance*, 31, 1023–1038. doi:[10.1037/0096-1523.31.5.1023](https://doi.org/10.1037/0096-1523.31.5.1023)
- Khan, A. Z., & Crawford, J. D. (2003). Coordinating one hand with two eyes: Optimizing for field of view in a pointing task. *Vision Research*, 43(4), 409–17.
- Krois, J. M. (2011). Bildkoerper und koerperschema. In H. Bredekamp & M. Lauschke (Eds.), *Bildkoerper und koerperschema* (pp. 23–271). Berlin: Akademie Verlag.
- Lawson, R., Bertamini, M., & Liu, D. (2007). Overestimation of the projected size of objects on the surface of mirrors and windows. *Journal of Experimental Psychology: Human Perception and Performance*, 33, 1027–1044. doi:[10.1037/0096-1523.33.5.1027](https://doi.org/10.1037/0096-1523.33.5.1027)
- Lenggenhager, B., Tadi, T., Metzinger, T., & Blanke, O. (2007). Video ergo sum. Manipulating bodily self-consciousness. *Science*, 317, 1096–1099. doi:[10.1126/science.1143439](https://doi.org/10.1126/science.1143439)
- Longo, M. R., & Haggard, P. (2009). Sense of agency primes manual motor responses. *Perception*, 38, 69–78. doi:[10.1068/p6045](https://doi.org/10.1068/p6045)
- Ramachandran, V. S., & Rogers-Ramachandran, D. (2000). Phantom limbs and neural plasticity. *Neurological Review*, 57(3), 317–320. doi:[10-1001/pubs.Arch Neurol.-ISSN-0003-9942-57-3-nnr8257](https://doi.org/10-1001/pubs.Arch Neurol.-ISSN-0003-9942-57-3-nnr8257)
- Ramachandran, V. S. (January 1, 2009). “Self Awareness: The Last Frontier, Edge Foundation web essay”. www.edge.org/3rd_culture/rama08/rama08_index.html Retrieved April 16, 2012
- Savardi, U., Bianchi, I., & Bertamini, M. (2010). Naive predictions of motion in mirrors. From what we see to what we expect reflections to do. *Acta Psychologica*, 134, 1–15. doi:[10.1016/j.actpsy.2009.11.008](https://doi.org/10.1016/j.actpsy.2009.11.008)
- Sutter, C., & Müsseler, J. (2010). Action control while seeing mirror images of one’s own movements: Effects of perspective on spatial compatibility. *The Quarterly Journal of Experimental Psychology*, 63, 1757–1769. doi:[10.1080/17470210903511244](https://doi.org/10.1080/17470210903511244)
- Tsakiris, M., & Haggard, P. (2005). The rubber hand illusion revisited: Visuotactile integration and self-attribution. *Journal of Experimental Psychology: Human Perception and Performance*, 31, 80–91. doi:[10.1037/0096-1523.31.1.80](https://doi.org/10.1037/0096-1523.31.1.80)
- Wnuczko, M., & Kennedy, J. M. (2011). Pivots for pointing: Visually-monitored pointing has higher arm elevations than pointing blind-folded. *Journal of Experimental Psychology: Human Perception and Performance*, 37(5), 1485–1491. doi:[10.1037/a0024232](https://doi.org/10.1037/a0024232)