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# Mirror, mirror, on the wall, is that even my hand at all? Changes in the afterimage of one's reflection in a mirror in response to bodily movement

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ABSTRACT

Successful mirror self-recognition has often been considered a correlate of self-awareness in human development and phylogeny (Gallup, 1982). Studies have also shown that vision and touch interact such that objects viewed in a mirror's reflection are recoded as originating from a location within reachable, or peripersonal, space (Maravita et al. 2002). However, the association of mirror self-recognition and self-awareness is controversial, and the mechanism that underlies the recoding of visual information into peripersonal space remains an open question. In the present study, we address these issues through the novel use of an old paradigm: positive afterimages. It has been shown that when a positive afterimage is induced, and a limb is displaced from its apparent location in the afterimage, the afterimage of the limb fades or "crumbles" (Davies, 1973). We reproduced this effect in conditions where subjects viewed the afterimage of their arms' reflection using a frontally placed mirror and mirror box (Ramachandran & Rogers-Ramachandran, 1996). Our results suggest that the explicit knowledge that one is looking at a mirror as well as online visual feedback from bodily movement are unlikely to be responsible for previously observed interactions between vision and touch. Instead, we propose that a sense of ownership, and (bodily) self-awareness, might in part explain these interactions between vision and proprioception, which provides a partial vindication of the inference from successful mirror self-recognition to self-awareness.


## 1. Introduction

While mirrors are ubiquitous and indispensable tool in many aspects of our daily lives, such ubiquity belies the impressive cognitive feats our use of mirrors presupposes. The familiar act of self-grooming, typically performed with the assistance of a bathroom mirror, is a clear example. When we enter the bathroom, there is never any confusion as to whether the figure observed in the mirror's reflection is oneself or someone else. While appearing to be observed at twice the distance to the mirror surface, we assume the tools seen in the mirror's reflection, like combs or toothbrushes, have a true location in reachable, or *peripersonal*, space. These common feats—of self-recognition and encoding the true location of objects—make mirrors an important tool and topic for cognitive science.

First applied by Gallup (1970) and Amsterdam (1972), the use of mirrors to test for self-recognition in infants and nonhuman animals has been an important paradigm for investigating self-recognition and awareness. The test consists of marking the face of an individual in a place only observable with the assistance of a reflective surface and then presenting the individual with a mirror. If the individual frequently displays behavior directed towards the mark, then it is thought that they are recognizing their reflection. After several decades of investigation, the ability to pass the "mirror test" has turned out to be a rarely demonstrated ability in other species. To date, convincing evidence of passing the mirror test exists only for chimpanzees and orangutans among nonhuman primates (Gallup, Anderson, & Shillito, 2002). More recent evidence suggests that distantly related mammalian species, bottlenose dolphins (Reiss & Marino, 2001) and Asian elephants (Plotnik, de Waal, & Reiss, 2006), are also able to succeed at the mirror task. Most infants succeed on the mirror test by their second year (Gallup et al., 2002). Since the ability of mirror self-recognition by infants and nonhuman species is not of adaptive benefit *per se*, passing the mirror test is an important tool due to the cognitive abilities it correlates with. Hence, given that the emergence of mirror self-recognition in human development correlates with empathetic behavior towards others, it has been claimed that the same holds true during phylogeny (De Waal, 1996). Similarly, others suggest that passing the mirror test, and exhibiting the capacity for self-recognition, presupposes self-awareness in nonhuman primates. In turn, theory of mind—the capacity to attribute mental states to

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others—is claimed to be a natural byproduct of being self-aware and recognizing mentality in ourselves (Gallup, 1982). However, drawing these connections between mirror self-recognition and theory of mind is controversial, and a more plausible suggestion is that self-recognition facilitated by the observation of congruences between vision and self-generated movement in infants and other species is the product of a bodily, rather than conceptual, sense of self (Tsakiris & Haggard, 2005). Yet, any such inferences are questionable without independent grounds for linking these capacities to the mechanisms that produce mirror self-recognition in infants and nonhuman species. In this regard, recent work on the "body schema" is highly relevant as a potential source of independent support for a connection between mirror self-recognition and bodily self-awareness, as evidence suggests that self-directed representations from multiple modalities interact and maybe integrated in self-information processing (Platek, Thomson, & Gallup, 2004).

Recent research on how the human brain integrates information from multiple sensory modalities supports the classical notion of the *body schema* (Head & Holmes, 1911), an internal representation of the posture and extension of the body in space (Maravita, Spence, Sergent, & Driver, 2002; Reed & Farah, 1995), which contrasts with our conscious awareness of our body, or "body image." Increasingly, such research has investigated how tool use, which allows us to extend and augment our possible space for action, and potentially results in the incorporation of tools into the body schema (Maravita & Iriki, 2004). Typically, interactions between visual and tactile processes are stronger for visual stimuli that are closer to the body, with cross-modal interference being greater if tactile and visual stimuli are spatially close in location (Pavani, Spence, & Driver, 2000). This is sensible given that tactile sensation requires physical contact which is only possible with objects in close proximity. However, mirrors present a clear deviation from this tendency. Maravita et al. (2002) found cross-modal interference involving visual distractors in a tactile discrimination task, where visual distractors were only visible through a mirror's reflection, was greater than when visual distractors were directly viewed at the same ocular distance (e.g. placed near rubber hands or those of an experimenter). This was interpreted as supporting the conclusion that this peculiar case of cross-modal interaction is not a product of merely low-level cues, such as ocular distance, but is also determined by higher level processes that recode indirectly viewed and distant visual stimuli. In this case, vision and touch interact as if objects viewed in a mirror's reflection originate from a location in close proximity to the body. One question left unaddressed by this result is the cause of this mirror interference effect. Maravita et al. (2002) suggested that the effect might be dependent on explicit knowledge that one is looking at a mirror, or temporally congruent visual feedback from the mirror and any movement generated during the experiment. While there is plenty of evidence that supports the latter proposal (Botvinick & Cohen, 1998; Ehrsson, 2007; Ramachandran & Rogers-Ramachandran, 1996), the relative role of explicit knowledge and visual feedback in the recoding of objects seen in mirrors still demands further investigation.

Addressing this issue and evaluating the suggestions made by Maravita et al. (2002) is of significant interest in its own right, and it might also shed light on the question of whether there are any good independent reasons for implicating some form of self-awareness in mirror self-recognition, since visual feedback, or explicit knowledge that one is looking at a mirror (or reflective surface, in the case of other species), might play a role in successful mirror self-recognition. To this end, we employed the paradigm of positive afterimages, which is often overlooked in work on multi-sensory integration. After dark adaptation, if a bright flash is discharged a positive afterimage develops which is akin to seeing the visual scene as though it were briefly illuminated by a weak light, even though the room is in fact completely dark. While no new visual input is available during the experience of positive afterimages, several interesting visual effects can be observed by manipulating proprioceptive input (Bross, 2000; Davies, 1973; Gregory, Wallace, & Campbell, 1959). For example, positive afterimages have been shown to conform to "Emmert's Law," which holds that a retinal image varies relative to the surface it is projected on: even in complete darkness, if a positive afterimage is "projected" onto a surface held by a subject, the "perceived" size of the afterimage will vary according to the distance of the surface (Bross, 2000). One striking effect is that if the positive afterimage of someone's outstretched hands develops, and then one of the hands is moved so that it is no longer spatially congruent with its apparent location in the afterimage, then the afterimage of the displaced hand and arm fades or "crumbles" (Davies, 1973). In more recent work, it has been determined that part of the explanation for why the crumble effect occurs is that visual and proprioceptive input to our high-order representation of our body as extended in space conflict after a limb is displaced from the position that was congruent with the visual representation of the limb's position. It is this conflict that causes the distortion of the positive afterimage, such that the conflict is "resolved" by a top-down altering of our visual representation (Hogendoorn, Kammers, Carlson & Verstraten, 2009). In the present study, we tested to see whether subjects would experience this crumble effect when the afterimage was the reflection of their hands on either a mirror box (Ramachandran & Rogers-Ramachandran, 1996) or a frontally placed mirror. If a crumble effect were observed in these cases, it would indicate humans have an attachment to their reflection in which explicit knowledge and visual feedback from movement are unlikely to play a causal role. The reasoning for this conclusion is as follows.

First, if subjects experience a crumble effect for the afterimage of the reflection of their hands in a frontally placed mirror, then they are recoding an indirectly viewed distant visual stimulus as having a true location in peripersonal space (since they would be encoding the reflection as being of their own body which is trivially in peripersonal space). This would be in line with the mirror effect reported by Maravita et al. (2002). Their results show that visual stimuli can modulate a tactile response to an observed body part, even though the visual and tactile stimuli are spatially disparate. However, a crumble effect in a frontally placed mirror would show the reverse: that a *proprioceptive* input can modulate a visual experience even though the proprioceptive and visual stimuli are spatially disparate. This would be especially interesting, given that vision is typically the dominant modality. And, since the visual scene is illuminated for only a fraction of a second, visual feedback of any bodily movement would ostensibly be ruled out as playing a role in the crumble effect since the scene is not illuminated long enough for any movement to be observed. Furthermore, since positive afterimages are only experienced for a few seconds, a crumble effect in a frontally placed mirror would show that the body schema can be extended to include objects viewed in the mirror during this minimal period, which contrasts with the training required to manipulate the body schema in other experiments—for example, the "rubber hand illusion", in which synchronized brushing of a covered arm and a visible rubber glove positioned above the arm causes subjects to experience the brushing as if the rubber glove had sensed the contact, requires a comparatively longer period of training to be experienced (Botvinick & Cohen, 1998). Second, using a mirror box to elicit a crumble effect—like that employed by Ramachandran & Rogers-Ramachandran (1996) in which the reflection of an external arm on the side of the box is congruent with the position of a subject's arm inside the box—would exclude explicit knowledge from playing a role in the crumble effect for one's reflection in a frontally placed mirror. If the afterimage of the reflection of the arm outside the mirror crumbles when the arm *inside* the box is moved, then explicit knowledge that one is experiencing the