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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

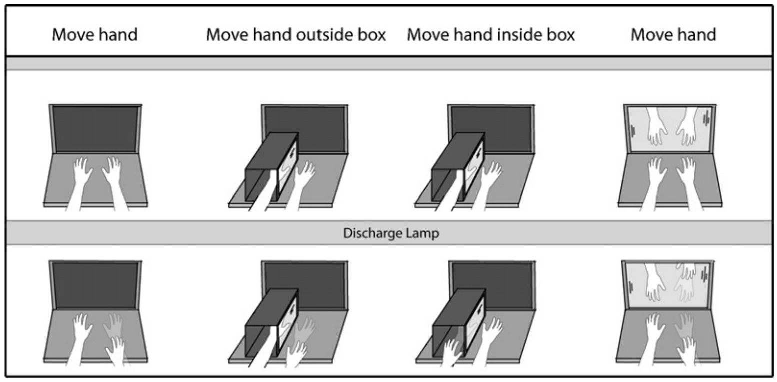

Fig. 1. Graphical depiction of starting and final position of the hands for each of the experimental conditions. The transparent hand in the lower panel indicates the perceived location of the displaced hand in the visual afterimage. Block 1: Replication of Davies (1973) Subjects displace one of their hands after the formation of the afterimage. Block 2: Mirror box (outside hand). Subjects displace the hand located outside of the mirror box after the formation of the afterimage. Block 3: Mirror box (inside hand). Subjects displace the hand located inside of the mirror box after the formation of the afterimage. Block 4: Subjects displace one of their hands after the formation of the afterimage. Vividness ratings are made on the reflection of their hand in the frontally placed mirror.

afterimage *of a mirror* cannot be playing a role, since if it were one would expect the afterimage of the reflection to remain stable. This is so because the reflection on the side of a mirror box depends on the presence of the static arm outside the mirror box, *not* the arm inside the box, and the change in the afterimage would contradict this. Hence, the crumble effect provides a simple and elegant means for investigating the roles that explicit knowledge and visual feedback from movement might play in mirror facilitated cross-modal interference, and mirror self-recognition.

2. Experimental methods

2.1. Subjects

Eleven naïve subjects ($n = 11$) participated in the experiment. All had normal or corrected to normal vision. Subjects were either undergraduate or graduate students at the University of Maryland, College Park and were paid for their participation.

2.2. Apparatus

Subjects were seated at a table in the corner of a light sealed room. The frontally placed mirror consisted of a 72 cm × 70 cm glass mirror located on the wall adjacent to the table and was aligned flush with its surface. While seated facing the mirror, neither the flashbulb, nor the experimenter was visible to subjects in the reflection. The mirror box consisted of a 30 cm × 60 cm × 30 cm cardboard box with a 30 cm × 60 cm Plexiglass mirror attached to one side. The inside of the mirror box as well as the surface of the table were marked with pieces of tape for aligning the thumb and index finger of both hands to minimize the discrepancy between the location of the hand inside the box, and the apparent visual location due to the reflection of the hand outside the box. Placement of the tape was also such that when the subjects' hands were in position, and eyes were fixated at the frontally placed mirror, they could not readily see both their reflection, and their hands. The frontal mirror was covered by a white fabric when not in use during a trial, and the mirror box was placed next to the table and positioned and removed by an experimenter. All surfaces in the visual field of the subjects, including the table top and wall, were white.

Positive afterimages were induced using a high intensity flash of light generated by a Speedotron 4803cx, which produces a 1000 W flash for a duration of approximately 1 ms. The lamp was placed on a stand behind the subjects and directed at the ceiling above the subjects' heads to reflect down on the table and frontally placed mirror. The experimenter sat behind subjects in the room in order to prepare each trial, discharge the flashbulb, administer directions, and record vividness ratings by subjects. All audio from each experiment was recorded in an adjacent room.

2.3. Design

A 1 ms discharge of the flashbulb causes a positive afterimage of the subjects' hands positioned above the table. In all subjects, the subjective experience following the flash is as follows: a "wash" or blind period (lasting 1–2 s), followed by the development of the positive afterimage which is akin to seeing one's hands and the room as when the flashbulb was discharged, but dimly illuminated (lasting 6–10 s).

In all trials, the manipulation was to move one of two hands after development of the positive afterimage, and to make vividness ratings for the afterimage of the moved/target hand or its reflection and that of the static/reference hand, or its reflection, while keeping eyes fixated. Subjects were instructed to displace the target hand at the point when they subjectively judged the positive afterimage to have become most vivid. Vividness ratings were made on a scale of 1–10 with a baseline rating of 5 determined by the vividness of the afterimage of a single hand placed on the table during two practice trials. While there is only limited data on the physiological processes that underlie positive afterimages (Dowling & Hubbard, 1963; Rushton, 1963), such measures were not necessary for our study, since differences in vividness ratings between the target and static hand were the focus of the experiment, ratings were entirely subjective, and subjects were free to use the 10 point scale at their discretion. The experiment consisted of four conditions (Fig. 1):

Condition 1: original. The first condition was based on condition 4 from Davies (1973). Subjects raised their hands 2.5 cm over the surface of the table and fixated at an imaginary point between them. After the development of the positive afterimage, subjects moved the target hand horizontally above the surface of the table to the side of their body while trying to avoid contacting the table or the side of their body with the moved limb. Vividness judgments were made for the afterimages of both the target and reference hands.

Conditions 2: Mirror box, outside hand. After aligning both hands using the tape markers on the table and inside the mirror box subjects fixated at an imaginary point between their hand and the anticipated location of its reflection on the mirror box. After development of the positive afterimage, the hand outside the box was moved by the subject either horizontally to their side or it was kept stationary. Vividness judgments were made for the afterimage of the hand outside the box, as well as its *reflection* on the side of the mirror box.

Condition 3: Mirror box, inside hand. Subjects aligned their hands in the appropriate positions inside and outside the mirror box and fixated between their hand and the mirror box's surface. After development of the positive afterimage subjects either moved the hand inside the mirror box or it remained stationary. As in condition 2, vividness judgments were made for the afterimage of the hand outside the box, as well as its *reflection* on the side of the mirror box.

Condition 4: frontal mirror. As in condition 1, subjects placed both hands above the surface of the table, but in this condition the frontally placed mirror was made visible by the experimenter. Subjects moved one of two hands to the side of their body after the positive afterimage developed. Importantly, in this condition subjects did not make vividness judgments for the afterimages of their hands on the table but for the reflections of the moved/target hand and static/reference hand in the frontally placed mirror. For all subjects, both hands, both arms, as well as their torso were visible in the afterimage of the mirror's reflection.

2.4. Procedure

Upon entering the room, subjects were familiarized with the mirror box, and the location of the frontal mirror, after which they were adapted in total darkness for 10 min. Also prior to dark adaptation, the start and final positions for the target arm were described, with subjects instructed to withdraw the target arm to the side of their body, per the description of condition 1 above; this was done to insure uniformity of movement between subjects. Prior to the commencement of experimental trials, two practice trials were performed with subjects experiencing the positive afterimage of one hand placed on the table in front of them. This served three functions: (1) After 10 min of dark adaptation the first few discharges of the flashbulb can be uncomfortable, and subjects can have difficulty keeping focused; these trials acquainted subjects with experiencing the procedure. (2) In these trials, subjects were instructed to keep the vividness of the afterimages of their hand that they had just experienced in mind as examples of what they should treat as a vividness rating of "5" on a 1–10 scale when making vividness ratings on future trials. They were instructed that "1" should be taken to correspond to the apparent absence of the afterimage, and that "10" should be taken to correspond to an incredibly vivid afterimage. (3) So that subjects were familiar with the general time course of the experience of positive afterimages; this allowed them some prior experience of when, during the development of positive afterimages, they appear most vivid. The room was kept in complete darkness, except when it was illuminated for 1 ms by the flashbulb, when a small LED light was used to assist subjects in finding a good fixation point in trials that involved the mirror box or frontally placed mirror, and briefly after subjects reported their vividness ratings for a trial when the experimenter used the LED to assist in recording the scores (subjects were instructed to cover their eyes during this time). A record of the subjects' responses were also recorded using a microphone attached to a computer in a separate room as a record of any additional descriptions they provided of their experiences.

Prior to the start of the each trial, the experimenter asked subjects if they were ready to continue, at which point, if subjects answered in the affirmative, a verbal countdown followed after which the flashbulb was discharged and the trial began. Subjects were instructed to report their ratings as soon as the afterimage had dissipated. For blocks 2–4, subjects were also asked whether they experienced afterimages of their reflections in the mirror box or frontally placed mirror. If they answered in the negative, then the trial was repeated. After subjects' vividness ratings for a trial were reported and recorded they were re-dark adapted for 2 min.

Subjects performed a block of four trials for each of the four conditions. Block 1 consisted of all trials for condition 1 (original), block 4 consisted of all trials for condition 4 (frontal mirror). The remaining mirror box conditions were blocked into trials with the mirror box over the left hand and trials with the mirror box over the right hand. Trials alternated between the left hand and right hand as target hand, and inside hand and outside hand as target hand. This resulted in trials for blocks 2 and 3 being "mixed", since conditions 2 and 3 concern the hand outside and inside the mirror box, respectively, and both arms cannot *both* be inside the mirror box, each trial in these blocks involved vividness ratings for *both* conditions, given that one hand was always outside the mirror box, and the other was always inside. For example, on trials in which the outside hand was the target, and the inside hand was static, the outside hand would be "part of" condition 2, while the inside hand would be "part" of condition 3. Block order was pseudo-random, with condition 1 occurring first for the majority of subjects (8/11). There were no qualitative differences in the outcome of the experiments between these subjects and those that began with one of the other three conditions.

3. Results

The effect of hand displacement and viewing condition (direct viewing versus mirror reflection) was tested with a two way repeated measures ANOVA. The results of the analysis showed a main effect for hand displacement ($F(1, 10) = 30.53$, $p < 0.001$), indicating the observer's hand movement altered the perception of the hand in all four conditions. There was no effect of viewing condition ($F(1, 10) = 0.20$, $p = 0.67$); there was, however, a significant interaction between hand displacement and viewing condition ($F(1, 10) = 7.511$, $p = p < 0.01$)), indicating the crumble effect scaled differently for reports based on direct viewing of the hand and those based on mirror reflection of the hand. This interaction is visibly apparent in (Fig. 2) in that there were larger differences in vividness ratings between the displaced and static hand for the two direct viewing conditions (conditions 1 and 2).

Post hoc comparisons of all four conditions revealed significant differences for subjects' average vividness ratings between the displaced and static hands in all of the conditions (Fig. 2). As expected, in condition 1, the displacement of a target hand decreased the vividness of the afterimage for the target hand relative to the static/reference hand to an extremely significant degree ($t(10) = 5.27$, $p < 0.001$). This is a quantitative replication of Davies' original observation. For condition 2, there was also a significant difference in vividness ratings of the hand outside the mirror box between trials in which it was moved versus static ($t(10) = 4.83$, $p < 0.001$). Significant differences were also observed for the vividness ratings of the target and reference hands for condition 3 ($t(10) = 3.23$, $p < 0.01$), and condition 4 ($t(10) = 3.00$, $p = 0.013$), the two conditions in which subjects' reports were based on the reflection of their hand in the mirror.

A comparison of difference in vividness ratings between conditions 1 and 2 showed no difference ($t(10) = 0.34$, $p = 0.74$), which was as expected, since in both conditions subjects experienced an

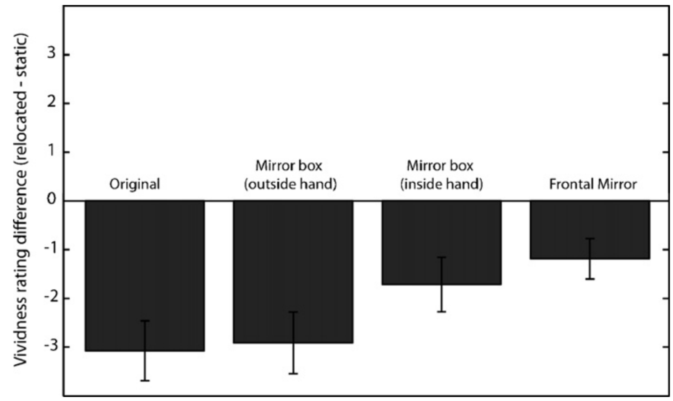

Fig. 2. Differences in vividness ratings between static and target hands for the four conditions. There was no significant difference between the difference scores for condition 1 (original) and condition 2 (mirror box, outside hand), the conditions that did not involve mirrors. The same is true between the difference scores for conditions 3 (mirror box, inside hand) and condition 4 (frontal mirror), the conditions that did involve mirrors.

afterimage of their actual hands, rather than a reflection. The difference in vividness ratings for conditions 2 and 3 (the mirror box conditions) was marginally significant ($t(10) = 1.92$, $p = 0.08$). A subsequent power analysis revealed that to have adequate statistical power (i.e. 0.8), with the current effect size ($d = 0.58$), would require a sample size of 20, nine more than the current sample size. Therefore, this effect is only marginally significant due to a small sample size. This marginal effect could be attributed to the imperfect alignment between the reflection of subjects' hand outside the box with their hand inside the box. A comparison of difference in vividness ratings for the two mirror conditions 3 and 4, also showed no significant difference ($t(10) = 0.98$, $p = 0.35$). A power analysis showed that, with a small effect size ($d = 0.30$), a sample size of 72 participants would be required to have adequate statistical power (i.e. 0.8). The lack of an effect in this condition, thus, could also be due to the small sample size.

4. Discussion

Mirrors present an interesting case where objects viewed indirectly and at a distance are recoded as having a true location in close, peripersonal space. In the present study, we sought to investigate this interaction between vision and proprioception by means of visual afterimages. Maravita et al. (2002) found that visual cues presented in a mirror and in close proximity to one's hands interact with tactile sensation in the same way as visual cues presented proximal to the body. Unanswered, however, was the question of the relative roles that explicit knowledge of looking in a mirror, as well as subtle temporal congruencies between visual stimuli and bodily movement, had in causing this mirror effect. We sought to address this same question as it arose in the case of mirror self-recognition, using an afterimage paradigm and the well confirmed crumble effect: if subjects experienced a crumble effect for the afterimage of the reflection of their displaced hand in a frontally placed mirror, then this would suggest that humans recode the afterimage of the reflection as being of their own hands, and it would be unlikely for this to be due to explicit knowledge or visual feedback. Our reasoning was that since the scene is only illuminated for a fraction of a second, there is not enough time for any visual feedback to correlate with bodily movement on the part of subjects. Also, if subjects experienced a crumble effect for the afterimage of the reflection of their arm on the side of a mirror box when the arm *inside* was displaced, then this would suggest that whatever processes are responsible for the crumble effect do not have access to the higher order information that one is viewing a mirror.

Critically, a crumble effect was observed with the frontally placed mirror and mirror box. Subjects' mean ratings of the vividness of the afterimage of their reflection were lower for the moved/target hand versus static/reference hand in trials that involved a frontally placed mirror, and those in which the hand inside the mirror box was the moved/target hand (Fig. 2). In line with the above reasoning, this suggests that neither explicit knowledge nor congruency between visual feedback and movement were playing a role in causing the crumble effect in the frontally placed mirror. Of course, in regards to the *acquisition* of the capacity to recode the location of objects seen in mirrors, visual feedback from movement will surely play a critical role. But the present results suggest that such visual feedback becomes unnecessary once the capacity has been acquired: recoding of one's reflection, and so alteration of the body schema, can be achieved in the short period of time in which the positive afterimage is experienced (see Carlson, Alvarez, Wu, & Verstraten, in press), without any possibility of observing congruent visual feedback and bodily movement. Instead, only a few seconds of static visual and proprioceptive input seem to suffice for establishing a connection between subjects' reflection in the mirror and their felt body posture. This contrasts markedly with effects such as the rubber hand illusion (Botvinick & Cohen, 1998) or induced out-of-body experiences (Ehrsson, 2007), which require comparatively extensive training, and is plausibly due to the ubiquitous role of mirrors in our everyday lives.

Changes in proprioceptive input are sufficient for causing changes in the quality of positive afterimages (Bross, 2000; Carey & Allan, 1996; Hogendoorn et al., 2009). In contrast, it is unlikely that efferent motor signals play a role, since passive versus active displacement has no appreciable effect on the quality of afterimages when it comes to the tendency of afterimages to follow Emmert's Law (Bross, 2000), or induction of the crumble effect (Hogendoorn et al., 2009). Hence, it is likely that the crumble effect is caused by visual processes being overridden by afferent proprioceptive inputs. This is of interest because of the relationship between efferent and afferent signals and higher order subjective experiences of agency and ownership. While normally phenomenologically indistinguishable, the sense of agency and ownership for an action can come apart, with the sense of agency being linked to the motor system and the sense of ownership with proprioception (Gallagher, 2000). The sense of ownership has previously been implicated in many bodily illusions that are the product of multi-sensory integration (Botvinick & Cohen, 1998), and more recently, Hogendoorn et al. (2009) found that loss of sense of ownership of the afterimage of a target hand coincided with the lack of a crumble effect when the hand was displaced. The sense of agency and especially ownership are both thought to underlie a minimal sense of bodily self (Gallagher, 2000; Tsakiris & Haggard, 2005), which suggests a partial vindication of the inference that self-awareness must underlie successful mirror self-recognition. That is, minimally, successful mirror self-recognition requires some sense of self, however it is mistaken to infer that this must be the notion that underlies conceptual self-awareness, or might provide the basis for theory of mind, given the many different conceptions of self which are relevant to cognitive science (Neisser, 1988). Instead, *some* notion of self might play a role. Since the crumble effect is likely driven by afferent proprioceptive inputs (Hogendoorn et al., 2009), and is plausibly mediated by a sense of ownership over the visual afterimage of our hands, a partial explanation for why subjects report a crumble effect with a frontally placed mirror is the sense of ownership they have over the afterimage of their reflection. In turn, a notion of (bodily) self underlies this sense of ownership. Recognizing ourselves in a mirror requires taking the reflection to be of our body, and by association, of ourselves.

While tentative, we take the present study to lend *independent* support to the thesis that such bodily self-awareness is a cognitive correlate of successful mirror self-recognition, in humans, and perhaps, other species. If correct, this supports a connection between the body schema and a multi-modal view of how we represent information about the self. Platek et al. (2004) investigated the effects of presenting one's own body odor, written name, and spoken name, on reaction time in a self-facial recognition task. They found that subjects were significantly quicker at recognizing their own face when it co-occurred with stimuli from other modalities that carried self-directed information. These results were interpreted as lending support to the idea that processing information about the self integrates information from many different sense modalities: a self "network." Though the experiments of Platek et al. (2004) focused on cross-modal effects in regards to facial recognition, while our focus was on visual and proprioceptive representations of limbs and their position, we believe that the results presented here offer a different, and supporting perspective on the hypothesis that self-awareness integrates information from multiple modalities. The hypothesized body schema, important for understanding how we represent the extension our bodies in space, is also thought to integrate (sometimes conflicting) inputs from multiple modalities. In this regard, the body schema, which is plausibly the basis for our bodily self-awareness and an embodied view of the self (Tsakiris & Haggard, 2005), might partially constitute the suggested network of self-directed processes.

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