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RESEARCH ARTICLE

Egocentric mental transformation of self: effects of spatial relationship in mirror-image and anatomic imitations

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Abstract Assessing the mental state of others by considering their perspective plays an important part in social communication. Imitation based on visual information represents a typical case of the translation of sensory input into action. Although humans are often successful in imitating complex actions, the mechanisms that underlie successful imitation are poorly understood. In earlier findings, it has been suggested that understanding others' minds through imitation is realized in the course of the comparison between the representations of the self and others, involving a transformation of the egocentric perspective to the allocentric one. There are two possible strategies of transformation between the representation of the self and others. One possible scenario is that the imitator perceives and imitates others as if looking in a mirror (mirror-image imitation, where, for example, the demonstrator's right hand corresponds to the imitator's left hand). Alternatively, the imitator might estimate the demonstrator's action using the anatomically congruent limb (anatomic imitation, where, for example, the demonstrator's right hand corresponds to the imitator's right hand). Here, we conducted a series of experiments in which the subjects imitated simple hand actions such as pushing a button presented from several different spatial orientations rotated at various angles. We observed that the imitators changed their strategy of imitation (mirror-image or anatomic imitation) depending on the nature of spatial configurations. Behavioral data from this study support the hypothesis that mirror-image and anatomic imitations provide complementary systems for understanding the actions and intentions of others.

Keywords Anatomic imitation · Mental own-body imagery · Mirror-image imitation · Perspective-taking

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Introduction

Understanding the intentions of others and considering their mental state by taking their perspectives play an important part in social communication. Humans are successful in imitating many complex skills in daily life; however, mechanisms that underlie successful imitation remain to be elucidated. Imitation based on visual information represents a typical case for the translation of sensory information into action. Action implies a goal and an agent; therefore, action recognition implies the recognition of a goal and the understanding of the agent's intentions. The discovery of mirror neurons has provided an effective model for the basic mechanism underlying perception–action coupling, which is involved in imitation and action understanding (Gallese et al. 1996; Rizzolatti et al. 1996). The mirror system allows a direct matching of the representation of observed and executed actions, thus providing a precursor mechanism for the human ability to imitate (Iacoboni et al. 1999; Rizzolatti et al. 2001).

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While there is the view that the human mirror neuron system plays an important role in imitation, imitation itself would basically consist of a sequence of cognitive processes that involve a spatial assessment of the object, importing kinetic information from the object, transforming the information from within and then replicating the action by imitators themselves. The parietal association area responsible for spatial image transformation is heavily involved in the perception–action coupling of imitation (Wohlschläger et al. 2003), whereas studies support an essential role of the inferior frontal gyrus (IFG) in imitative facility (Iacoboni et al. 1999; Molnar-Szakacs et al. 2005).

In earlier studies, imitation was suggested to be realized during the comparison of the representations of the self and others, involving a transformation of the egocentric perspective to the allocentric one (Meltzoff and Moore 1994). During the transformation process from the representation of the action of others to the action of the self, there are two alternative strategies that can be used for imitation (Fig. 1). One possible scenario is that the imitator perceives and imitates others as if looking in a mirror, for example, the demonstrator's right hand corresponding to the imitator's left hand. Alternatively, the imitator may estimate the demonstrator's action using the anatomically congruent limb, for example, the demonstrator's right hand corresponding to the imitator's right hand. There is evidence from psychological studies that a preference for mirror-image imitation over anatomic imitation is observed in both children and adults (Avikainen et al. 2003; Schofield 1976). Studies of goal directed imitation in children showed that young children prefer to imitate the demonstrator's action using the mirror-image translation process; however, older children and adults gradually learn to follow the anatomic imitation process (Bekkering et al. 2000; Wohlschläger et al. 2003). These tendencies might be related to the properties of the mirror neuron system located in the frontal area (Koski et al. 2003), where the function of the mirror neuron system is more general than a simple "mirroring" of action.

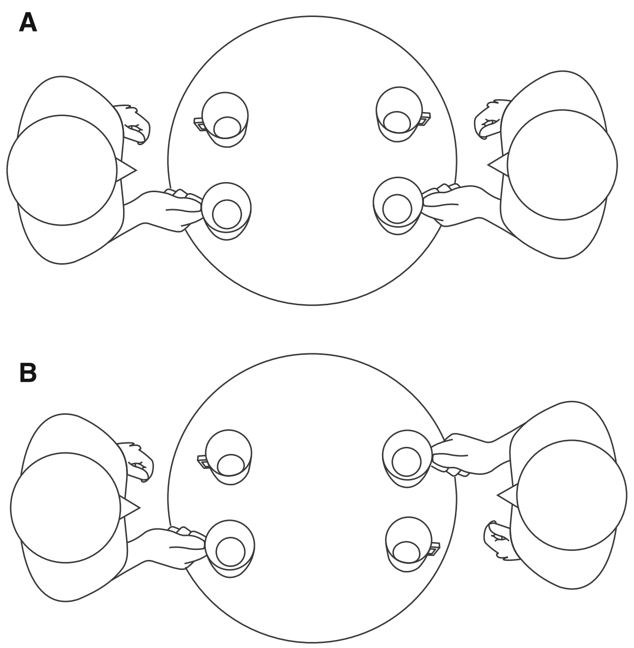

Fig. 1 Two possible processes of transformation between the representation of the self and others. **a** Mirror-image imitation: The imitator perceives and imitates the other as if looking in a mirror, for example, the demonstrator's right hand corresponding to the imitator's left hand. **b** Anatomic imitation: The imitator estimates the demonstrator's action using the anatomically congruent limb, for example, the demonstrator's right hand corresponding to the imitator's right hand

On the basis of these findings, we conducted a series of experiments using the two different (mirror or anatomical) imitation strategies. In daily situations, action observation occurs in miscellaneous orientation angles; therefore, it is important to study the properties of the imitation system at various orientation angles. It is interesting to observe how the two alternative (mirror-image or anatomic) imitation strategies are employed at intermediate orientation angles.

In these experiments, the subjects were asked to imitate a series of simple hand actions, for example, pushing a button presented from several different spatial orientations rotated at various angles using mirror-image and anatomic imitation. We analyze how successful imitations are accomplished depending on the perspective and strategy. Finally, we discuss the general relationship between the role of perspective-taking and the fundamental aspects of social cognition, such as considering other's mental state through processes for mental own-body imagery.

Methods

Subjects

Eight healthy subjects (3 females and 5 males) participated in this study. The mean age of this group was 27 years (range, 24–30 years). All of the subjects provided informed consent prior to their inclusion in this study. The subjects were all right-handed (as determined by the Edinburgh Handedness Inventory) and had normal or corrected-to-normal vision.

Procedure

The subject and the experimenter, performing as the demonstrator, sat in front of a round table (1 m in diameter). They both had a box with 4 buttons arranged symmetrically in a line (Fig. 2a). The experimenter pushed buttons with either their right or left index finger in a random order. The subjects were instructed to observe and imitate the experimenter's hand movement as rapidly and accurately as possible using either the mirror-image or anatomical imitation strategies.

At the beginning of each session, the subjects were instructed as to which kind of imitation they were required to perform. The experimenter's button press action was repeated 24 times in each session. The inter-stimulus intervals were set at 5 s. The imitation sessions were conducted in various spatial relationships with relative orientation angles of 45, 90, 135 and 180° in the clockwise and counterclockwise directions (Fig. 2b, c). The session with the relative orientation angle set at 180° was considered to be the facing situation, and the session with a relative orientation angle of ±45° was considered to be the side-by-side situation. The remaining sessions with relative orientation angles of ±90° and 135° were considered to be the intermediate situations. The procedure was designed to investigate the nature of imitation as it gradually changes depending on perspective and strategy, during imitative trials in the intermediate orientations between the "facing" and "side-by-side" conditions.

Each session consisted of 24 trials that were conducted for every relative orientation angle and both kinds of imitation, resulting in a total of 672 trials. 2 blocks of mirror-image imitations and 2 blocks of anatomic imitations were conducted alternately. All sessions in each block were conducted in the clockwise and counterclockwise order starting from the adjacent position. To facilitate the subjects' performance, a warm-up session was conducted until obvious errors, for example, incorrect button pressings or the use of the wrong hand, were eliminated (Fig. 3). The warm-up session was conducted for an average of 4 trials per session. The experimenter's and the subject's movements were recorded by a digital video camera positioned approximately 1 m away from the table, which facilitated the examination of whether there were any obvious errors. When there were obvious errors, the session was started again. We measured and analyzed the nature of subject's responses in the imitation sessions. We recorded the response latency from the time when the experimenter pressed a button until the subject pressed the corresponding button.

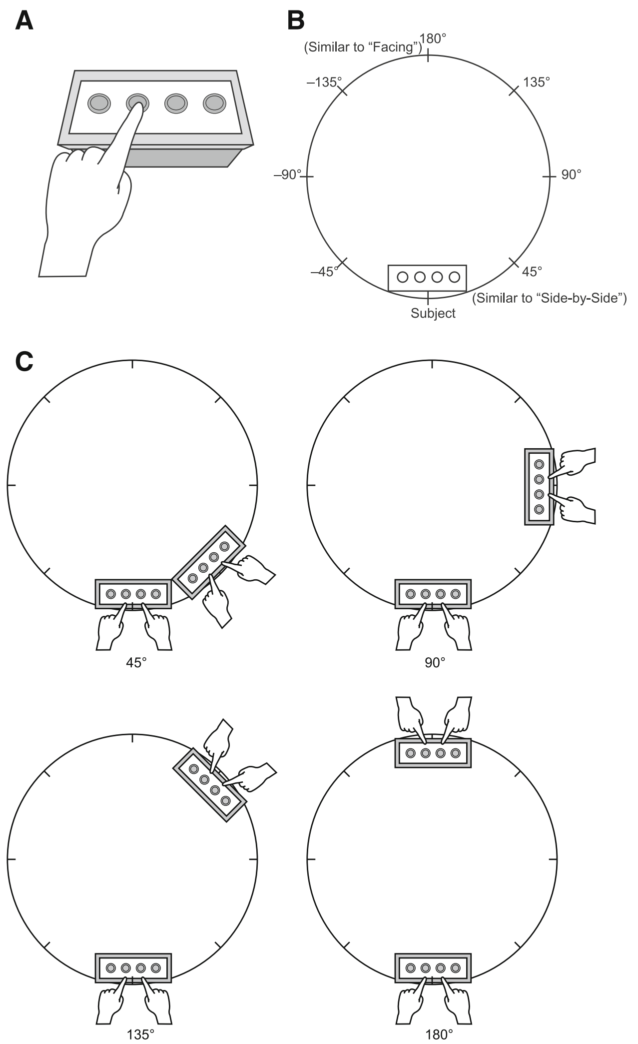

Fig. 2 Material and experimental setup. **a** Subjects sat in front of a box with 4 buttons arranged symmetrically in a line on a round table. **b**, **c** Spatial orientations in the mirror and anatomical imitation tasks

Results

The mean response latencies for all subjects in the facing and side-by-side situations are shown in Fig. 4. In both of these visual perspectives, the analysis of response latencies showed a significant effect for the imitation strategy used (Fig. 4a). According to repeated-measures ANOVA of the imitation strategies, the subjects were significantly faster with the mirror-image imitation (522.5 ± 65.2 ms) than

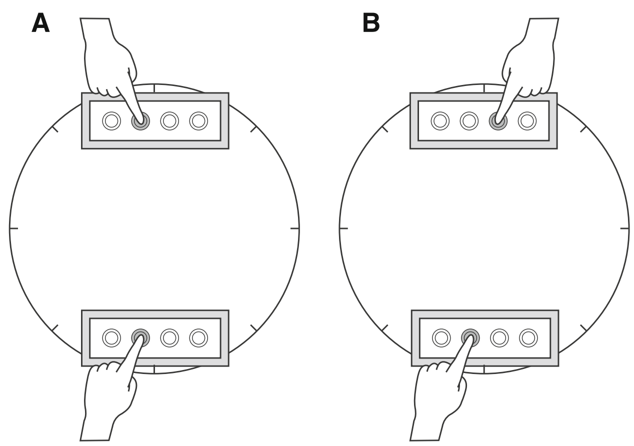

Fig. 3 Examples of correct responses in the tasks. **a** Mirror-image imitation. **b** Anatomic imitation

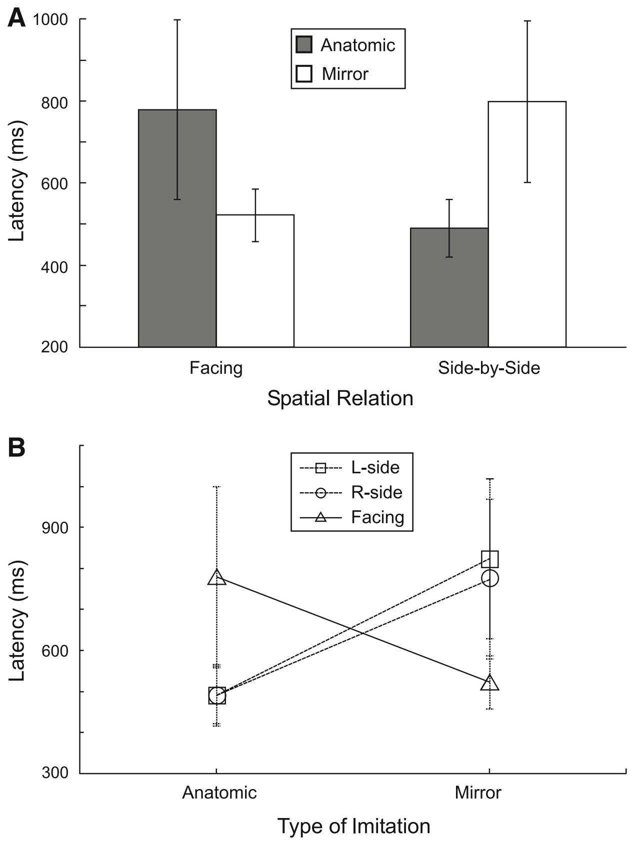

Fig. 4 Comparison of the facing with side-by-side situations. **a** Mean value of the response latency during the facing situation (180°) and side-by-side situation (±45°). **b** Effects of the subject's relative position during the side-by-side situation (*right* or *left*)

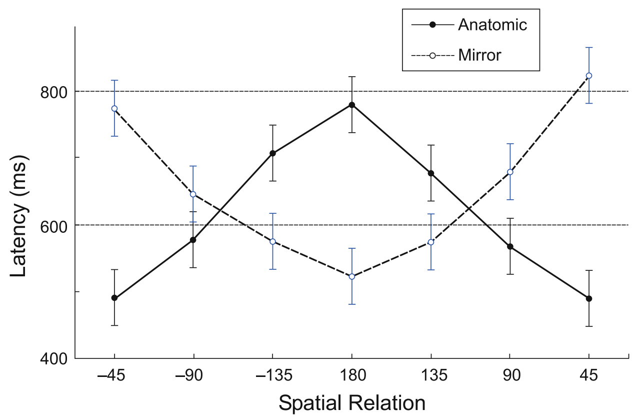

Fig. 5 Response latency during the 2 imitation strategies. Mean values of the response latency at all relative orientation angles (*solid line* anatomic imitation; *dashed line* mirror-image imitation)

with the anatomic imitation (779.8 ± 219.4 ms) in the facing situation (F (1,14) = 4.60, $p = 0.01$). On the contrary, subjects were significantly faster with the anatomic imitation (489.6 ± 70.4 ms) than with the mirror-image imitation (799.0 ± 196.8 ms) in the side-by-side situation (F (1,14) = 4.60, $p < 0.005$). There was a significant effect of interaction between the positional relationship of the subject and the experimenter and the imitation strategies (F (1, 28) = 4.20, $p < 0.001$). Furthermore, examination of the relationship exclusively within the side-by-side situation revealed no significant difference for position between the subject and the experimenter during the anatomic imitation (F (1,14) = 4.60, $p = 0.99$) and the mirror-image imitations (F (1,14) = 4.60, $p = 0.64$) (Fig. 4b). Tukey post hoc tests confirmed these significant differences.

Linear regression analysis revealed strong correlations between the absolute values of relative orientation angles and response latencies. There was a negative correlation for mirror-image imitations ($r = 0.979$ for the plus direction, and $r = 0.979$ for the minus direction) and a positive correlation for anatomic imitations ($r = 0.997$ for the plus direction, $r = 0.995$ for the minus direction) (Fig. 5).

Discussion

The present study described a behavioral experiment that investigates the effects of perspective and strategy on imitation. There is a spatial compatibility between the observed and required action in the following two conditions: the mirror-image imitation in the facing situation and the anatomical imitation in the side-by-side situation. In these conditions, the spatial compatibility has made it possible for the subjects to conduct the required actions with faster reaction times. At various relative orientation angles, the subjects may have implicitly performed a mental transformation of their perspective either by imagining themselves in the demonstrator's body position or by imagining the demonstrator's body as a reflection or rotation of their own body. In the first case, mirror-image imitation would demand a reflection symmetry, where the subjects have to imagine themselves in the other's body position and to take their visuospatial perspective (third-person perspective), relating the action presented by the demonstrator to the own-body image. Alternatively, an anatomic imitation would require a rotational symmetry, where the subjects have to maintain their own visuospatial perspective (first-person perspective) and superimpose the own-body image on the action presented by the demonstrator. The respective subsets of our data would reflect these specific types of object mental rotation mechanism (Shepard and Metzler 1971).

Consistent with the results of a previous study (Jackson et al. 2006), the reactions of the subjects during the mirror-image imitation were significantly faster than during the anatomic imitation in the facing situation. In the side-by-side situation, on the other hand, the mirror-image imitation took significantly longer. The effect of the angles of relative orientation revealed a pair of symmetrical aspects in the graph (Fig. 5), suggesting the existence of complementary systems between mirror-image and anatomic imitations.

Verbal reports from the subjects after the sessions were consistent with the tendency for the two alternative imitation strategies revealed at intermediate angles. The subjects typically answered that the configuration was "almost side-by-side" at 45 degrees, "more side-by-side than facing" at 90 degrees, and "more facing than side-by-side" at 135 degrees. These verbal reports reveal the cognitive processes subserving the switching between alternative (mirror-image vs. anatomical imitation) strategies depending on the angles.

The results reported here are consistent with the 'generalist' theory of imitation put forward in previous studies (Brass and Heyes 2005; Newman-Norlund et al. 2010; van Elk et al. 2011). The flexibility of the switching between alternative imitation strategies, coupled with a robust handling of the spatial configuration, is compatible with the idea that the observed behavior is a manifestation of a general learning and motor control mechanisms. The switching of the hand of action is a general behavioral requirement observed in many daily activities, rather than a special strategy specifically designed for imitation.

During imitation, subjects need to translate a complex dynamic visual input pattern into motor commands for the self-performed movement sequence. Previous studies mainly dealt with imitative behavior in the facing situation (Avikainen et al. 2003; Jackson et al. 2006; Koski et al. 2003). These behavioral studies reported that the complex translation process from visual inputs to motor commands causes a delay in imitative behavior in the facing situation. In comparison, our experimental sessions were conducted for various spatial relationships with relative orientation angles in addition to the facing situation that were not assessed by previous studies.

Our findings are closely related to the sense of the embodied self and the representation of others. The embodiment of one's own body is the foundation of the first-person perspective (Vogeley and Fink 2003; Grèzes and Decety 2001) and subserves the cognitive processes relating one's body to those of others. The "own body" is considered to be involved in several phenomenological aspects of the self, for example, self-location, self-other distinction, and self-other interaction. Embodied self-location may be somehow crucial for social cognitive abilities. Several imaging studies have suggested that visuospatial perspective-taking requires spatial cognitive abilities that rely on bodily processing, such as mental body transformations and mental imagery with a disembodied self-location (Arzy et al. 2006; Blanke et al. 2005).

Since the discovery of mirror neurons in the ventral premotor cortex (area F5) and parietal area PF of the monkey (Gallese et al. 1996; Rizzolatti et al. 1996), there has been a growing debate as to whether they may be the neural basis for the ability to imitate. The perception and execution of actions have been considered to possess a common representational domain, operating with a mechanism to transform visual information directly into motor acts (Bekkering et al. 2000). This conceptual idea was confirmed by brain imaging studies (Iacoboni et al. 1999; Iacoboni et al. 2001; Nishitani and Hari 2000). Similar results indicating that mirror neurons play a crucial role in imitation were obtained using repetitive transcranial magnetic stimulation (rTMS) (Heiser et al. 2003). The suggestion that the mirror neuron system overlaps with the neural representations of observed and self-performed actions has provided a physiological model for the basic mechanism underlying perception–action coupling, which is involved in imitation, action understanding, and reading the intentions and mental states of others (Amodio and Frith 2006; Frith and Frith 2006; Gallese and Goldman 1998; Iacoboni et al. 2005; Uddin et al. 2007). The activities of the mirror system may be significantly affected by the relative orientations of the actor and observer.

The properties of imitation process revealed in this study provide clues to how we handle cognitive challenges when facing actors at various orientation angles. Recent investigations revealed that the mirror neuron system processes the how, what, and why of other people's actions. Ultimately, the robust handling of the reflection and rotation of one's own body, dealing with miscellaneous cognitive challenges in complementary ways, would subserve a close connection with the "how" and "what" aspects of imitations and mind reading.

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