Individual Differences in Self-Recognition from Body Movements

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Abstract

Since we rarely view our own body movements in our daily lives, understanding the recognition of self-body movement can shed light on the core of self-awareness and on the representation of actions. We first recorded nine simple and nine complex actions performed by individual participants, who also subsequently observed nine videos displayed on the screen and imitated these actions. After a delay period of 35-40 days, participants were asked to identify their self- body movements presented as point-light displays amongst three other actors who performed the same actions. Participants were able to recognize themselves solely based on kinematics in point-light displays. However, self-recognition accuracy varied according to the complexity of performed actions, with more accurate self-recognition for complex than simple actions. The ability of self-recognition with simple actions showed a significant relation with autistic traits (negative relation: poorer self-recognition accuracy with more autistic traits), schizophrenic traits (quadratic non-linear relation, participants with the median degree of schizophrenia traits performed better than participants at the extremes), and with imitation actions and motor imagery traits (linear relation: increased self-recognition accuracy with greater motor imagery). We also found that participants did not recognize actions that only required visual experience but could identify their self-generated actions that required motor experience, underscoring the importance of motor experience to the representation of self-body movements.

Keywords: self-recognition, body movement, action, individual differences

Introduction

Of the fundamental prerequisites of human existence, the recognition of the "self" is a crucial pre-reflective, automatic process, underlying human perception and cognition. The ability to self-recognize is fundamental to the construction of an identity, agency, self-awareness, and self-consciousness (Gallup, 1970), and impairments in self-recognition ability can impact the quality of social interaction and communication (Ornitz & Ritvo, 1968)

Constructing the "self" is complex, accounted for by various disciplines all attempting to instantiate a definition. For example, examining a singular construct such as self-consciousness, has been extensively studied in humans, other primates, dolphins, and even extended to non-human agents, such as robots. Importantly, most of these accounts of self-processing are rooted in recognition-based self-face processing (e.g., Uddin, Iacoboni, Lange, and Keenan, 2007), famously standardized by Gallup (1970) in his prototypical mirror mark test. However, only relying on self-face recognition as an index for identifying the self is limited to serve as a general account for the integrated self-processing based holistically on face, body, voice and even body movements.

Given the dynamism of our everyday environment and lack of privileged access to viewing our bodies in motion, movements of our own body may serve as a good measure without relying on rich visual experiences of the self. In this vein, several studies extended self-recognition from static faces to whole-body movements, with visual input reduced to dynamic dot movements, as in point-light displays. After participants' body movements were recorded with a motion capture system, participants were still able to recognize their own action, even with scant visual information (Cutting & Kowlowski, 1977). Such above-chance performance for self-recognition extracted from predominantly from body kinematics was found for many different actions that varied in complexity (Loula et al., 2005; Burling, Kadambi, Safari, & Lu, 2018).

The impact of intrinsic traits to self-recognition ability, on the other hand, is less studied in the literature. There are a number of reasons as to why it is important to measure individual difference traits in self-body recognition. First, the unique contribution of various individual difference measures can uncover critical information that could potentially be lost through group-level averaging (Peterzell, 2016). Additionally, self-recognition is a complex process, with its investigation particularly hampered by its own operationalization and resulting lack of objectivity (consisting of no clear-cut computational investigation).

What individual differences might impact self-recognition from body movements? The joint contribution of both action perception and understanding likely recruits a distinct neural system, with the most prominent account surrounding the mirror neuron system. The mirror neuron account of action understanding suggests that perception and action are tightly linked through a "mirroring", simulation-based mechanism that allows humans to understand the kinematic goals of actions (Rizzolatti & Craighero, 2004). Impairments in this mirroring mechanism may underlie social perception disorders such as Autism and Schizophrenia. Consistent with this view, previous behavioral research in biological motion perception has shown that individuals with Autism (Blake et al., 2003, Moore et al., 1997) and individuals with Schizophrenia demonstrate impairments in biological motion perception, such as in discriminating communitive actions from non-communicative actions presented in point-light displays (Okruszek et al., 2015).

The ability to interpret social actions not only shows impairment in individuals clinically diagnosed with Autism Spectrum Disorder and Schizophrenia, but also individual differences amongst typical populations in those with varied degrees of autistic traits (Miller & Saygin, 2013; Ahmed & Vander Wyk, 2013; van Boxtel, et. al., 2017), as well as schizophrenic traits, which impacts self-face processing (Platek & Gallup, 2002). Given the individual differences in biological motion perception in the general population, it is possible that people may show differing ability in self-recognition of own body movements. To date, only one other study (Burling et al., 2018) has compared self-recognition performance of body movements between people with high degree of autistic traits and people with low autistic traits. This study found a significant difference at the performance level between the two groups of participants. However, no study has systematically mapped out any other individual difference measures and run a large sample of participants to examine the individual differences in self-recognition from body movements.

In the present study, we included three different individual difference measures: autistic traits, schizophrenic traits, and motor imagery traits, all of which are linked to both social perception and likely functions of the mirror neuron system. Three main research questions were addressed. First, how well can people identify themselves from only the kinematics of body movements, and does the performance of self-recognition depend on the complexity of performed actions? Second, to what extent does the interplay between motor (more mirror-based) and visual experience (more perception-based) determine the performance of self-recognition from actions? Finally, how do individual differences in the ability to recognize own-actions displayed in point-light stimuli relate to motor imagery ability and distinct socio-cognitive traits (autistic and schizophrenic)?

Experiment

Method

Participants 71 undergraduate students ($M_{\text{age}} = 20.98$) were recruited through the Subject Pool at the University of California, Los Angeles. The study was approved by the UCLA Institutional Review board. All participants were provided course credit for their participation, and were naïve to the purpose of the study. Participants had normal or corrected-to-normal vision and no physical disabilities.

Procedure The experiment was split into two sessions: motion recording and action recognition. The first phase consisted of a motion recording session, where participants performed various actions and were recorded with a motion capture system. The second phase, consisted of two action recognition components. The first component, the self-recognition session, occurred after a delay period of 30 – 45 days. The stimuli were first generated in the action recording session and subsequently tested in the self-recognition task. Immediately, following the self-recognition task, participants completed the final action recognition task, consisting of a visual recognition" task.

Materials

Apparatus Participants' body movements were recorded using the Microsoft Kinect V2.0 and Kinect SDK in a quiet testing room. Here, participants were instructed to perform the actions in a rectangular 2.5 x 5 ft space, in order to provide flexibility to perform the action, while remaining within recording distance. The Kinect was placed 5 ft above the floor and 8.5 ft away from the participant. The three-dimensional (X-Y-Z) coordinates of the key joints were extracted at a rate of approximately 33 frames per second and later used to generate point-light displays of actions (see Figure 1). Customized software developed in our lab was utilized to enhance movement signals, and to carry out additional processing and trimming for actions presented later in the testing phase (van Boxtel & Lu, 2013).

Stimuli Generation For each participant, 27 point-light displays performing different actions were captured based on their body movement recordings. The first nine actions were simple actions which included *grab, jump, wave, lift, kick, hammer, push, point, punch.* The next nine actions were complex actions, which included: *argue, macarena, wash windows, play baseball, get attention, hurry up, fight, stretch, and play guitar*. These actions were selected in part based on a previous self-recognition study (Burling et al., 2018), but four actions (*macarena, wash windows, play baseball, play guitar*) were modified to be more constrained from their original actions (*dance, clean, play sport, play instrument*) in order to reduce the impact of memory cues. The actions varied in complexity in order to characterize a broad range of common movements in daily life. During action selection, simple and complex actions were determined by whether the action was a simple goal (e.g., wave) or a complex goal (e.g., argue), and all actions were selected to be commonly encountered actions.

The final nine actions were labeled imitation actions, which included *jumping jacks, basketball, bend, direct traffic 1, direct traffic 2, conversation, laugh, digging a hole, and chopping wood.* The nine imitation actions were selected from the Carnegie Mellon Graphics Lab Motion Capture Database available online (http://mocap.cs.cmu.edu) and also captured a broad range of variability and goal-directed actions. Some imitation videos were easily recognizable to subject (e.g., basketball), while others were unclear in what they conveyed (e.g., directing traffic). Each video displayed a stick figure performing one of the imitation actions and was presented in three different angles to the subject, either to the right or left (+/- 45°) or facing forward (0°) by rotating the horizontal axis. The varying viewpoints were included in order to assess the inherent viewpoint dependence in self-recognition. Each imitation action was recorded twice: once after viewing the three different angles, and once more after viewing only the forward-facing angle. In the self-recognition phase, the first imitation recording served as practice, and only the second imitation recording was utilized.

Following action recording and prior to the self-recognition session, we filtered noise from the movements by applying a double exponential adaptive smoothing filter (LaViola, 2003), in order to remove recording errors from the Kinect system (e.g., missing a joint due to occlusion or small jitter for some joints). Additionally, the stimuli were trimmed in order to display the point light-displays (van Boxtel & Lu, 2015) with their segmented action recording, which would be reiteratively looped in the self-recognition session.

Procedure

Motion Recording Session

For the 18 simple and complex actions in the first recording session, participants were provided verbal instruction and instructed to perform the actions as naturally as possible. As a result, the action was open to interpretation, in order to emphasize the lack of a systematic way to perform the action. For the remaining nine imitation actions, all the participants were naïve to the name of the action. Instead, participants were visually instructed to *imitate* the actions (however they chose to imitate), in order to emphasize their naturalistic response to "imitation." After completing the action recording, participants completed two questionnaires: Schizotypal Personality Questionnaire (SPQ) and the revised Vividness of Motor Imagery Questionnaire (VMIQ-2). The SPQ was administered to assess degrees of schizotypal traits among individuals in the typical population. The VMIQ-2 was included to assess motor imagery differences as a potential source of variability in biological motion perception. Since perception and motor imagery representations presumably share common resources, we hypothesized that there may be correlations between the two abilities (Miller & Saygin, 2013; Iacoboni & Dapretto, 2006).

Recognition Session: Self-Recognition Task

In the subsequent self-recognition task, participants returned after a delay period of 30-45 days later in order to minimize the effect of memory on performance. Participants were seated 2.5 feet in front of a monitor in a dimly lit room and were asked to select their own action amongst three other distractor actions spread out horizontally along the center of the screen, as shown in Figure 1.

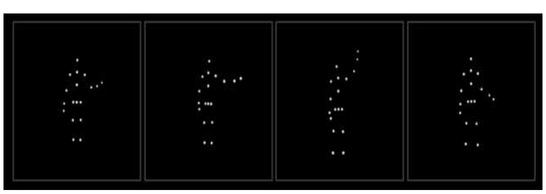

Figure 1. Illustration of a sample trial showing wave action (wave). One point-light display is the participant's action, while the other three point-lights are distractor actions normalized for gender, width, and height.

Each action was presented with 17 point-lights located at key joints, in three different orientations (rotated around the vertical axis 0°, (facing front), 45° (facing right), 225° (facing left), for a total of 81 trials. However, all of the actions within a trial displayed the same orientation. The actions were looped until the participant selected one of the four boxes, or until a time period of 30 seconds. Participants were not provided any feedback. Participants were instructed to select their own point-light action amongst four displays. The four animations included their own action and the corresponding actions performed by three other distractor actions that were normalized for height and gender.

Recognition Session: Visual Recognition Task

44 of the participants also participated in an additional visual recognition task consisting of nine trials displaying only the forward-facing imitation actions. The order of presentation of the visual recognition task was counterbalanced to either follow or precede the self-recognition task. Since imitation is a unique behavior that consists of both action observation and action performance, this additional task was included to assess whether performance would differ from the self-recognition task, and to understand the contribution of motor experience to self-recognition accuracy. Including this task could potentially allow us to contrast action observation in conjunction with execution (self-recognition task) with solely action observation (visual recognition task). Participants were instructed to identify the actor previously shown during the imitation recording amongst three other actors who performed the same action. Importantly, while the visual layout of the task was identical to the self-recognition session, the participants' own action was replaced by the original imitation actor from the Carnegie Mellon Database. As a result, participants' own point-light display was never amongst the four actions displayed on the screen. The remaining three distractor actions were maintained from the self-recognition session.

Following testing in the self-recognition and visual recognition task, participants were asked to complete an Autistic Quotient (AQ) questionnaire to assess the degree of Autistic traits (Baron, Cohen et al., 2001).

Individual Difference Measures

Autistic Quotient The Autism-Spectrum Quotient (AQ) questionnaire consists of 50 questions and is the most commonly used method to measure self-reported autistic traits (Baron-Cohen et al., 2001). Recent evidence has identified an overlapping genetic and biological etiology underlying ASD and autistic traits (Bralten et al., 2017) in addition to behavioral overlap (Baron-Cohen et al., 2001). Several studies of biological motion perception have reported an association between AQ scores and performance on various tasks (Miller & Saygin, 2013; Ahmed & Vander Wyk, 2013; van Boxtel et al., 2017). The AQ measures five different subtypes (social skill, attention switching, attention to detail, communication, and imagination).

Schizotypal Personality Questionnaire The Schizotypal Personality Questionnaire (SPQ) is a 74-question survey, designed to screen for schizotypal personality disorder in the general population. The SPQ is administered to assess degrees of schizotypal traits among individuals in the typical population. It measures three constructs of schizotypy: cognitive, perceptual dimension (positive schizotypy), interpersonal dimension (negative schizotypy), and disorganized feature dimension (odd behavior, speech) based on DSM-IV criteria (Raine, 1991). The SPQ consists of nine different subtypes (ideas of reference, social anxiety, odd beliefs, unusual perceptual experiences, eccentric behavior and appearance, no close friends, odd speech, constricted affect, and suspiciousness/paranoid ideation).

Vividness of Motor Imagery Questionnaire The VMIQ-2 (Roberts, 2008) is designed to measure vividness of imagery in kinesthetic (movement simulation), internal (first person simulation), and external (third person simulation) visual imagery of 12 different actions in a series of three separate sections. Vividness of motor imagery is rated on a five-point Likert scale for each of the 12 actions in each of the three sub-areas (lower scores indicate more vivid images). According to simulation theory, perception and motor imagery representations share common resources (Miller & Saygin, 2013; Iacoboni & Dapretto, 2006). Therefore, the VMIQ-2 was included to assess motor imagery differences as a potential source of variability in biological motion perception.

Results

Self-recognition from body movements

Average self-recognition accuracy was .46 (*SD* = .12), significantly above chance level of .25 ($p < .001$), indicating that participants were able to self- recognize primarily on the kinematics of their body movements. As shown in Figure 2, participants were able to recognize all actions significantly above chance performance: for simple actions with verbal instruction (*M* = .40, *SD* = .15), for complex actions with verbal instruction (*M* = .56, *SD* = .16), and for imitated actions with visual display (*M* = .41, *SD* = .16). One-way ANOVA results revealed a significant main effect of action type (simple, complex, and imitation) on self-recognition performance, $F(2, 140) = 44.66$, $p < .001$, $\eta_p^2 = 0.389$. Specifically, self-recognition was more accurate for complex than simple actions (*t*(?) = ***, $p < .001$) and imitation actions (*t*(?) = ***, $p < .001$).

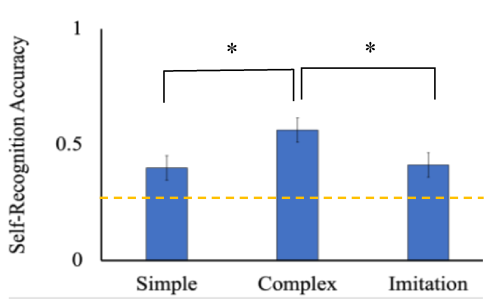

Figure 2. Self-recognition accuracy by the type of Action. Dashed line indicates chance performance (0.25). The error bars indicate ??? (standard error of means??, or 95% confidence interval??) in the paper.

To examine whether the visual representation of own-body movements was viewpoint- invariant or viewpoint-specific, we conducted a one-way ANOVA consisting of orientation (facing left: 225°, front: 0°, right: 45°) on self-recognition performance $F(2, 140) = .335$, $p = .716$. We found that people recognized their own actions equally well from different viewpoints, suggesting a viewpoint-invariant representation of self-generated actions. A previous study similarly found that recognition of walking patterns from self-generated point-light displays was independent of the viewing angle. This is likely due to simulating the motor action through referring to three-dimensionally stored motor representations (Jokisch, Daum, & Troje, 2004).

We compared recognition of imitation actions from motor experience (as in the self-recognition task), and recognition of imitation actions from the visual experience task (where subjects had to identify the imitation action they observed but was not their own). We found people recognized actions less accurately from visual experience (*M* = .239) than from self-generated (*M* = .404) actions (*t*(?) = ***, $p < .001$). Due to around-chance performance for identical actions with only visual experience, prior visual experience does not appear to be sufficient for self- recognition. This suggests that motor experience may constrain visual experience and is critical to the recognition of one's own action. Importantly, every individual has experience with their own motor actions. Identifying oneself may require the ability to simulate the action onto one's own motor system, with self-recognition in turn dependent on a matching process- matching simulated action to performed action.

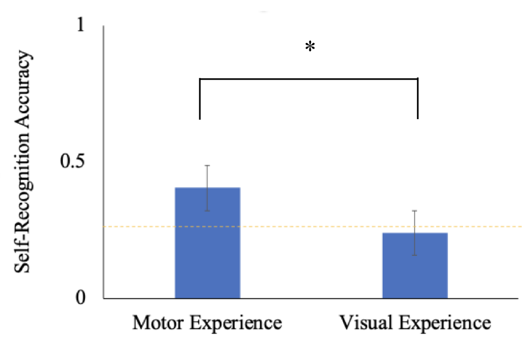

Figure 3. Self-recognition accuracy by experience type (visual vs motor). Significantly worse performance for imitation actions from visual experience than for self-recognition from performed actions. Dashed line indicates chance performance (0.25).

Relations between self-recognition and individual difference measures

We did not find any significant correlations between self-recognition performance for complex actions and the individual difference measures. However, we found significant relations between self-recognition performance for simple actions with various individual difference measures. As shown in the top panel of Figure 3, a significant relationship was revealed between overall motor imagery ability and self-recognition performance for imitation actions (spearman ρ = -.241, p = .043). For simple actions, a significant negative relationship emerged (Figure 3, middle) between the degree of autistic traits (AQ score) and self-recognition performance (spearman ρ = -.244, p = .040), revealing that people with more autistic traits performed less accurately in self-recognition with simple actions. To further probe the impact of autistic traits on self-recognition performance, we examined specific subtypes of the Autistic Quotient. We found a significant correlation between simple actions and the communication AQ subscale scores (spearman ρ = -.316, p = .007), but not with other subscale scores. For individual differences in schizophrenia traits, as shown in Figure 3 bottom plot, the trend analysis revealed a significant quadratic relationship between schizophrenia traits (SPQ score) and self- recognition performance, ($F(2,68)$ = 4.166, p = .020) , with participants scoring near the median of SPQ scale performing better than participants at the extremes in self-recognition. More discussion about the non-linear relation is included in the discussion section.

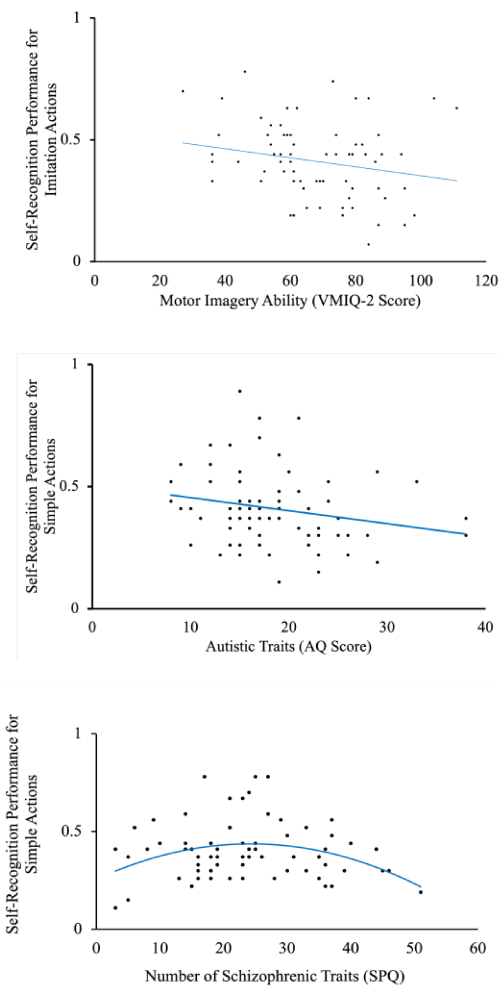

Figure 4. Relations between self-recognition performance and individual difference measures. Top: Positive relationship between motor imagery simulation and self-recognition for imitation actions. Middle: Negative relationship between autistic traits and self-recognition for simple actions. Bottom: Quadratic relationship between schizophrenic traits and self-recognition for simple actions (worse self-recognition at the extreme scores)

Discussion

The ability to self-recognize is integral to the construction of oneself as a unique entity, separate from the external world. Utilizing dynamic actions construed through self-generated point-light displays is a significant improvement over prototypical indices of self-recognition. Therefore, in the present study, we adopted the motion capture paradigm to examine how well people can identify themselves from only the kinematics of body movements from a range of commonly encountered actions. We found that participants were able to reliably self-recognize solely based on kinematics in point-light displays, in line with previous findings (Burling et al., 2018; Loula et al., 2005; Cutting & Kowlowski, 1977). Self-recognition accuracy also varied according to the complexity of performed actions, with more accurate self-recognition for complex than for simple actions, also corroborating a recent study (Burling et al., 2018). Since the complex and simple actions differed based on their variability, greater self-recognition for complex actions may be driven by the unique movement signatures available from these actions and increased motor planning (lack of automaticity) while performing complex actions. Importantly, the biometric identity cues in simple actions (e.g. walking) may not be readily apparent to the human visual system to recognize and differentiate these actions involving little variability (Dittrich, 1993; Loula et al., 2005). Therefore, participants exhibited greater self-recognition performance for the rich visual input conveyed by complex action sequences.

To assess the mechanisms underlying self-action recognition, we examined the contribution of visual and motor experience. Previous literature has indicated that people rely on motor experience when recognizing their own-body actions, as evidenced by greater recognition performance for self-generated point-light displays (reliant on motor experience) over close friends (reliant on visual experience) and strangers, presumably due to an internal simulation of the action (Loula et al., 2005). Conceptually, this is straightforward, as humans generally do not have privileged access to observe own locomotion movements from a third-person perspective, and consequently, experience little visual feedback (Jokisch, Daum, & Troje, 2004).

Therefore, to systematically contrast the relative importance of visual versus motor experience, we included an additional visual recognition task, wherein participants were asked to identify the imitation action they observed in the action recording session. We found that participants did not recognize actions that only required visual experience (actions they previously imitated, but that were not their own). Instead, participants were only able to identify their self-generated actions that required motor experience, underscoring the importance of motor experience to the representation of self-body movements.

Finally, we measured individual differences in self-recognition performance. We looked at three correlates of variability in the general population: motor imagery (as measured by the VMIQ-2) and two social perception traits (autistic and schizophrenic traits). Both Autism and Schizophrenia are linked to dysfunctions of the mirror neuron system and impairments in social perception. Because action perception is presumed to involve an internal simulation on one's own motor repertoire, we hypothesized reduced simulation ability in individuals high on the Autistic Quotient and Schizophrenic Quotient.

Success in self-recognition with simple actions showed a significant relation with autistic traits (negative relation: poorer self-recognition accuracy with more autistic traits), schizophrenic traits (quadratic non-linear relation: participants with the median degree of schizophrenia traits performed better than participants at the extremes), and motor imagery traits (linear relation: increased self-recognition accuracy for imitation action with greater motor imagery).

We found that self-recognition performance for simple actions was affected by the participant's degree of autistic traits, in line with results from a recent study by Burling and colleagues (2018). One possible explanation could be due to a general processing style in autism, as decreased attention directed toward social stimuli in high-AQ individuals (see Chevellier et al., 2012) or weakened top-down influence (Lu, Tjan, Liu, 2006) and adaptability to social enviroment in autism (Thurman, et. al., 2016, van Boxtel, et. al., 2013) . Although typical human adults are sensitive to social information in actions (Thurman & Lu, 2014; Su, van Boxtel & Lu, 2016), such ability is impaired in autism which could result in the worse performance in self-action recognition for people with high degree of autistic traits. Another explanation may pertain to a specific and mechanistic account, an underlying dysfunction in the mirror neuron system, with an impairment in self to other matching. A useful indicator related to the simulation-component of the mirror neuron system, is motor imagery, presumably reliant on an internal simulation of one's own motor system of the activated action (Jeannerod, 2001; Miller & Saygin, 2013). Specifically, the relationship between poorer self-recognition performance for simple actions and individuals with high autistic traits may be linked to worse motor imagery ability, as we found greater self-recognition accuracy with increased motor imagery ability. Additionally, in the clinical population, a previous study (Conson et al., 2013) found that subjects with Autism Spectrum Disorder exhibited alterations in mental hand rotation, specifically linked to impairments in motor action simulation. Further characterizing the link between motor imagery deficits and autistic traits in the general population may shed light on the underlying mechanisms of motor imagery and mirror neuron impairments in Autism.

We conjecture that worse performance for individuals with high schizophrenic traits may be due to over-simulation and motor imagery deficits (Sack et al., 2005), leading to delusions and hallucinations- a mark of positive schizotypy. For worse performance on simple actions with a low degree of schizophrenic traits, we hypothesize a lack of motor imagery ability as vividness of motor imagery is theorized to be an independent trait marker of Schizophrenia and simple actions may require a greater degree of simulation to dissociate between distractors (Sack et al., 2005).

Our study did not reveal any significant correlations between complex actions and the individual difference measures. Since complex actions may rely more on distinctive movement cues customized for different individuals, or long-term memory (specifically memory of how one would perform the action), it is likely that participants need not rely on motor simulation.

Collectively, the present results demonstrate that motor experience is an important component to understanding the core of self-body processing. Importantly, the perceptual representation of self-generated actions is affected by the degree of three key individual difference measures linked to the action understanding account of the mirror neuron system: autistic traits, schizophrenic traits, and motor imagery traits.

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