From Motor Imitation to Social Cognition: The Role of Self-Other Control [Postprint]

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Abstract

In social interactions, individuals exhibit a tendency to automatically imitate others' actions. Although this automatic imitation facilitates the understanding of others' action experiences, it can sometimes conflict with one' s own action intentions. Therefore, it is necessary to distinguish between one' s own action intentions and others' actions and to regulate the conflict between them. This ability is termed self-other control (SOC). Similar to action imitation control, higher-level social cognition such as theory of mind, perspective-taking, and empathy also involves processing information related to self and others. Numerous evidence indicates that SOC may be a domain-general processing mechanism, whereby the brain utilizes the same SOC system for distinguishing self and other information and regulating conflicts in both action imitation control and other social cognitive processes. Recent studies have found that, compared to inhibitory control that suppresses prepotent responses, SOC represents a more critical factor in social cognition, with the effect of inhibitory control on social cognition being modulated by SOC. Moreover, the domain-generality of SOC suggests that simple action imitation control training could be employed in the future for rehabilitation of individuals with impaired social cognition (e.g., individuals with autism and alexithymia).

Full Text

From Motor Imitation to Social Cognition: The Role of Self-Other Control

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Abstract: In social interaction, people have a tendency to automatically imitate others' actions. Although this automatic imitation facilitates understanding others' experiences, it can also conflict with one' s own action intentions. Therefore, we need to distinguish our own action intentions from those of others and regulate potential conflicts between them. This capacity is termed self-other control (SOC). Similar to imitation control, higher-level social cognition such as theory of mind, perspective-taking, and empathy also involves processing information about self and others. Much evidence suggests that SOC may be a domain-general mechanism, meaning that the brain uses the same SOC system across action imitation control and other social cognitive processes to distinguish and regulate conflicting information about self and other. Recent studies have found that, compared to inhibitory control—which suppresses prepotent responses—SOC is a more critical factor in social cognition, and the effect of inhibitory control on social cognition is moderated by SOC. Furthermore, the domain-generality of SOC suggests that future rehabilitation for individuals with social cognitive deficits (such as autism and alexithymia) could employ simple motor imitation control training.

Keywords: imitation control; self-other control; inhibitory control; social cognition

Imitation plays a vital role in human social interaction (Hamilton, 2008; Over & Carpenter, 2013), and learning others' behaviors through imitation is a crucial component in the development of social cognition (Marsh, Bird, & Catmur, 2016). Numerous studies have shown that people have a tendency to automatically imitate others' actions (Brass, Zysset, & von Cramon, 2001; Brass, Derrfuss, Matthes-von Cramon, & von Cramon, 2003; Brass, Ruby, & Spengler, 2009; Genschow et al., 2017; Heyes, 2011). This automatic imitation is closely related to the activity of the mirror neural system in the human brain (Rizzolatti & Craighero, 2004; Perry et al., 2017). Through mirror processing, our brains can match action perception with action execution, which helps us experience others' actions firsthand and understand the reasons or intentions behind their behavior (Pawling, Kirkham, Hayes, & Tipper, 2017). However, mirror processing also creates a problem: when others' actions are inconsistent with our own, the representations activated by our own actions conflict with those activated by observing others. Therefore, to ensure smooth execution of our own actions, we must control the impulse to automatically imitate, which is called imitation control. In imitation control, our brains need to distinguish between self and other action representations and regulate potential conflicts between them. This capacity is termed self-other control (SOC; de Guzman, Bird, Banissy, & Catmur, 2016).

Humans are social beings who constantly interact with others in daily life. During social interaction, not only others' actions but also their emotions, perspectives, and beliefs are continuously changing. To understand others' behavioral intentions and mental states while successfully achieving our own goals, we must be able to distinguish and regulate representations of self-related and other-related information (de Guzman et al., 2016). Interestingly, recent evidence suggests that SOC in imitation control may be a domain-general processing mechanism, where action imitation control and higher-level social cognition such as perspective-taking, theory of mind, and empathy share the same SOC system (Brass, Derrfuss, & von Cramon, 2005; Brass et al., 2009; de Guzman et al., 2016; Santiesteban et al., 2012; Spengler, von Cramon, & Brass, 2009). For example, studies have found that training in action imitation control can significantly improve individuals' performance in spatial perspective-taking tasks (Santiesteban et al., 2012) and empathy for others' pain (de Guzman et al., 2016).

SOC simultaneously considers both self and other in social interaction and should theoretically be a crucial component of social cognitive processing. However, most social cognition researchers still focus on the role of executive functions such as inhibitory control. One important reason why SOC has not yet attracted widespread attention is that, as a relatively new concept, research on the relationship between SOC and social cognition is still in its early stages, lacking empirical data to reveal the specific mechanisms of SOC in social cognition. Therefore, this article aims to review previous research on SOC, examining evidence for SOC as a common processing mechanism across different social cognitive domains including imitation control, perspective-taking, theory of mind, and empathy. Based on comparison with inhibitory control, we discuss the possible mechanisms of SOC in these social cognitive processes and propose new directions for future research, hoping to encourage more scholars to attend to the role of SOC in social cognition.

2. Self-Other Control in Action Imitation Control

Research has found that self-generated actions, observing others'actions, and imitating others' actions all activate the inferior parietal lobule and inferior frontal gyrus (Caspers, Zilles, Laird, & Eickhoff, 2010; Molenberghs, Cunnington, & Mattingley, 2009), which are brain regions responsible for mirror processing (Rizzolatti & Craighero, 2004; Fabbri-Destro & Rizzolatti, 2008; Rizzolatti & Sinigaglia, 2010). In other words, both observing and imitating others' actions can activate identical representations in an individual' s mind, known as shared representations (Brass & Heyes, 2005; Brass et al., 2009; Spengler et al., 2009). Clearly, shared representations facilitate our firsthand understanding of others' action experiences. However, they also create a problem: because mirror processing is automatic (Gallese, Rochat, & Berchio, 2013), when others' actions are inconsistent with our own action intentions, automatic imitation of others can interfere with our own action execution. At this point, we must employ SOC to distinguish and regulate self and other action representations.

2.1 Measuring Self-Other Control in Action Imitation Control

The classic task for measuring imitation control processing is the imitation-inhibition task (Brass, Bekkering, Wohlschläger, & Prinz, 2000). This is a motor interference paradigm. The typical procedure is as follows: first, a static hand appears at the center of the screen as an initial stimulus. Then this hand performs a finger-lifting movement (lifting either the index or middle finger). Simultaneously, a response signal (the number "1" or "2") appears between the index and middle fingers. Participants are instructed to respond only according to the signal: lift the index finger when seeing "1" and the middle finger when seeing "2" . Therefore, the finger indicated by the response signal can be either congruent or incongruent with the movement of the stimulus hand.

The logic of this paradigm is that if participants automatically imitate the stimulus hand' s movement, then in congruent conditions this automatic imitation would facilitate their own finger-lifting movement, whereas in incongruent conditions it would interfere. This motor interference paradigm has been widely used in imitation research, with consistent findings that participants show slower reaction times and higher error rates in incongruent compared to congruent conditions (Brass et al., 2001; Brass et al., 2003; Brass et al., 2005; Deschrijver, Wiersema, & Brass, 2017a; Genschow et al., 2017). This phenomenon is called the congruency effect (Butler, Ward, & Ramsey, 2016; Deschrijver et al., 2017a; Genschow et al., 2017). Clearly, a stronger congruency effect indicates poorer imitation control ability.

2.2 Brain Regions Involved in Self-Other Control Processing During Action Imitation Control

Neuroimaging evidence further reveals the relationship between imitation control and processing of self and other. For example, fMRI studies consistently find that imitation control activates the anterior frontomedian cortex (aFMC) and temporo-parietal junction (TPJ), both brain regions related to self and other information processing (Brass et al., 2005; Brass et al., 2009; Spengler et al., 2009). ERP studies also find that imitation control can elicit changes in the P300 component, with P300 amplitude being significantly suppressed in incongruent compared to congruent conditions when others' actions conflict with participants' actions (Deschrijver et al., 2017a; Deschrijver, Wiersema, & Brass, 2016, 2017b). In social cognitive processing, P300 is considered an electrophysiological index reflecting the brain' s distinction between self- and other-related representations (Knyazev, 2013). Research has found that the neural generators of P300 are located in aFMC, TPJ, and adjacent regions (Mulert et al., 2004; Perrin et al., 2005). Deschrijver (2017a) suggests that P300 suppression in incongruent conditions may be related to cognitive resource depletion caused by processing conflicts between self and other action representations.

Brass et al. (2009) found that aFMC and TPJ have different functions in imitation control processing. By adapting the imitation-inhibition task, Brass created two stimulus presentation methods. In the first method, when the stimulus hand began moving, a green or red "×" randomly appeared between its index and middle fingers. When the "×" was green, participants had to completely imitate the stimulus hand' s movement (congruent condition). When red, participants had to make a different movement: lift the middle finger when the stimulus hand lifted the index finger, and vice versa (incongruent condition). In the second method, the stimulus hand initially remained motionless while "1" or "2" response signals appeared between its fingers. As in the imitation-inhibition task, participants lifted their index finger when seeing "1" and middle finger when seeing "2". Only after participants responded did the stimulus hand perform its finger-lifting movement, which could be congruent or incongruent with the participant's previous action. Results showed that TPJ activation was higher in the second presentation method than in the first, while aFMC showed the opposite pattern with higher activation in the first method (Brass et al., 2009). Brass argued that in the second method, others' action information appeared after participants' responses, so automatic imitation could not conflict with participants' own actions. The enhanced TPJ activation in this condition may reflect the brain's identification processing of the identity (other/self) of others' action representations. In the first method, where others' actions occurred simultaneously with participants' actions, enhanced aFMC activation may reflect regulation of conflicts between self and other action representations.

3. The Relationship Between Action Imitation Control and Social Cognition

SOC is considered the "missing link" between the mirror neuron system and social cognition (Brass et al., 2009; Spengler et al., 2009). Although the concept of SOC developed from imitation research, recent studies indicate that SOC reflected in action imitation control has domain-generality, with different types of social cognition potentially sharing the same SOC system. This has important implications for understanding the internal processing mechanisms of social cognition.

3.1 Domain-Generality of SOC in Action Imitation Control

Similar to imitation control, higher-level social cognition such as perspective-taking, theory of mind, and empathy also requires us to control the processing of self and other information in real-time according to our goals when others' perspectives, beliefs, or emotional states differ from our own (Brass et al., 2009; de Guzman et al., 2016; Santiesteban et al., 2012; Sowden & Shah, 2014). Therefore, these social cognitive processes also require SOC to distinguish between self and other representations and regulate conflicts between them. For example, fMRI empirical studies and meta-analyses have found substantial overlap in aFMC and TPJ activation between action imitation control and perspective-taking, theory of mind, and empathy (Brass et al., 2005; Brass et al., 2009; Spengler et al., 2009). Research on autism has found that individuals with autism not only show deficits in social cognition such as theory of mind and empathy (Bradford, Hukker, Smith, & Ferguson, 2018; Happé, 1994; Smith, 2009; Schulte-Rüther et al., 2017; White, Hill, Happé, & Frith, 2009), but also have difficulty controlling automatic imitation of others' actions (Bird, Leighton, Press, & Heyes, 2007; Leighton, Bird, Charman, & Heyes, 2008; Sowden, Koehne, Catmur, Dziobek, & Bird, 2016; Spengler, Bird, & Brass, 2010). Moreover, in terms of brain activation, individuals with autism show weaker activation in aFMC and TPJ during both action imitation control and theory of mind reasoning (Castelli, Frith, Happé, & Frith, 2002; Spengler et al., 2010).

The strongest evidence for SOC' s domain-generality comes from two behavioral intervention studies (de Guzman et al., 2016; Santiesteban et al., 2012). These studies found that training in action imitation control could significantly improve individuals' spatial perspective-taking and pain empathy abilities. In de Guzman et al. (2016), participants first saw a stimulus hand on screen that then lifted either its index or middle finger. One group was asked to completely imitate the stimulus hand' s movements (SOC-weakened group), while another group was asked to lift the opposite finger (SOC-strengthened group). Results showed that compared to the SOC-weakened group, the SOC-strengthened group showed significantly increased electromyographic responses to empathy materials in a pain empathy task and higher scores on self-report empathy scales. Using the same training paradigm, Santiesteban et al. (2012) found that action imitation control training significantly improved participants' performance on a spatial perspective-taking task—the Director task. These results suggest that SOC is likely a universal mechanism by which our brains process interactive information about self and other in social interaction. Based on existing research, Happé et al. (2017) proposed how SOC participates in action imitation control, theory of mind, and empathy processing. In imitation control and empathy, recognizing others' actions and emotions gives individuals representations of others' actions and emotions, but also triggers automatic imitation of those actions and emotions (emotional contagion), leading to simultaneous representations of both self and other in the individual' s mind. For theory of mind, although processing others' beliefs does not trigger automatic imitation, individuals still need to represent both self and other beliefs simultaneously. Therefore, Happé et al. (2017) argue that although action imitation control, theory of mind, and empathy differ in specific processing procedures, successful completion of all three requires SOC to distinguish and control representations of self and other information.

3.2 Implications of SOC' s Domain-Generality for Understanding Social Cognition

Due to SOC' s domain-generality, it becomes possible to use the imitation-inhibition task to measure individuals' SOC capacity. By measuring performance in action imitation control, we can to some extent predict individuals' higher-level social cognitive abilities. More importantly, based on SOC' s domain-generality, we can conduct action imitation control training for individuals with impaired social cognition (such as autism and alexithymia) to improve their social cognitive abilities. Compared to other training methods, motor-level training is obviously simpler and more economical. Currently, some researchers have begun using the congruency effect in imitation-inhibition tasks as an index of SOC to explore its relationship with higher-level social cognition. For example, de Guzman et al. (2016) found that the stronger an individual' s congruency effect in the imitation-inhibition task, the stronger their empathic response to others' pain. In other words, lower-level SOC leads to greater fusion between self and other emotions (Steinbeis, 2016), with individuals becoming more emotionally involved with others. Genschow et al. (2017) obtained similar results using the Interpersonal Reactivity Index (IRI; Davis, 1980), finding that the congruency effect in imitation-inhibition tasks significantly correlated with total IRI scores and with the Empathic Concern (EC) and Personal Distress (PD) subscales. Additionally, Genschow et al. (2017) found that the congruency effect in imitation-inhibition tasks could significantly predict scores on the Autism-Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). However, Deschrijve et al. (2017a), using ERP technology to examine the congruency effect' s manifestation in the P300 component, failed to replicate the correlation between the congruency effect and AQ scores.

Overall, some researchers have begun to emphasize SOC's role in social cognition, but empirical evidence remains limited and some conclusions show discrepancies. Therefore, more evidence is needed to reveal SOC' s specific functioning patterns in social cognitive processing. Next, we discuss possible functioning patterns of SOC in social cognition by comparing it with another ability related to social cognition—inhibitory control (IC).

4. Different Roles of SOC and Inhibitory Control in Social Cognition

Social cognitive ability is crucial for human survival and development. For decades, researchers have used various experimental paradigms and tasks to explore the processing mechanisms underlying social cognition. The relationship between executive functions, particularly inhibitory control, and social cognitive abilities such as perspective-taking, theory of mind, and empathy has received extensive attention (Conway, Catmur, & Bird, 2019). Inhibitory control is an important component of executive function, reflecting the ability to suppress one' s own prepotent responses (Diamond, 2006; Miyake et al., 2000). It can help us overcome interference from our own mental states when understanding others' behaviors or intentions (Brown-Schmidt, 2009; Wang et al., 2008). Common measurement methods include go/no-go and Stroop tasks. Numerous studies have confirmed close relationships between inhibitory control and higher-level social cognitive processes including perspective-taking, theory of mind, and empathy (Benson, Sabbagh, Carlson, & Zelazo, 2013; Nilsen & Graham, 2009; Symeonidou, Dumontheil, Chow, & Breheny, 2016; Wilson, Andrews, Hogan, Wang, & Shum, 2018; Huang & Su, 2012; Su & Yu, 2015).

4.1 Relative Independence of SOC and Inhibitory Control

Inhibitory control belongs to the category of self-control (Doebel & Munakata, 2018; Nigg, 2017) and does not consider the distinction and regulation of other-related information. Unlike inhibitory control, SOC reflects our brain's ability to distinguish and regulate information about both self and other in interactive contexts. Therefore, theoretically, SOC—which considers both parties in social interaction—should be a more critical component in social cognition than inhibitory control. Because before we can use inhibitory control to overcome interference from our own mental states to understand others' mental states, we should first distinguish between representations of self and other mental states and regulate potential conflicts between them. Santiesteban et al. (2012) directly compared the roles of SOC and inhibitory control in spatial perspective-taking through a behavioral intervention study. In addition to SOC-strengthened/weakened groups, they included an inhibitory control training group (color-word Stroop task). After training, the SOC-strengthened group showed significantly better spatial perspective-taking performance than the other two groups, which did not differ significantly from each other. This demonstrates that SOC plays a more prominent role than inhibitory control in spatial perspective-taking.

Moreover, research has found that SOC and inhibitory control have different cognitive and neural underpinnings. First, previous studies found that brain activation during imitation-inhibition tasks overlaps substantially with that during theory of mind, perspective-taking, and empathy in aFMC and TPJ—two brain regions related to self and other information processing (Brass et al., 2009; Spengler et al., 2009). Since TPJ is responsible for identifying the identity (self/other) of self- and other-related representations (Decety & Lamm, 2007; Steinbeis, 2016), while aFMC regulates conflicts between self- and other-related representations (Brass et al., 2009; Spengler et al., 2009), these regions are considered to underlie SOC processing. Because SOC is domain-general, it can be measured through simple imitation-inhibition tasks. In contrast, tasks reflecting inhibitory control abilities such as Stroop and go/no-go tasks are primarily associated with prefrontal function (Brass et al., 2005; Casey et al., 1997). Additionally, brain lesion studies have found double dissociations between action imitation control and inhibitory control in some patients with prefrontal lesions: some patients perform poorly on imitation-inhibition tasks but normally on Stroop tasks, while others show the opposite pattern (Brass et al., 2003). Finally, research on autism has found that individuals with impaired social cognition often show over-imitation tendencies and cannot effectively control automatic imitation of others' actions, and this deficit in imitation control is related to functional impairments in aFMC and TPJ (Castelli et al., 2002; Spengler et al., 2010). Collectively, these results suggest that SOC and inhibitory control may be two independent abilities. Although both can influence social cognition, SOC appears to play a stronger role than inhibitory control.

4.2 SOC's Moderation of the Relationship Between Inhibitory Control and Social Cognition

As two factors influencing social cognition, it remains unclear how SOC and inhibitory control specifically interact in social cognitive processing. However, we can infer from existing work: when understanding others' mental states, we must first distinguish representations activated by others' mental states from those activated by our own, and regulate potential conflicts between them, before we can choose to suppress our own mental representations to better process others' mental representations. Therefore, theoretically, inhibitory control should operate on the basis of SOC processing in social cognition, with SOC exerting top-down modulation on inhibitory control' s effects. A recent study from our laboratory confirmed this view (Wang & Su, submitted). We measured participants' SOC and inhibitory control abilities using imitation-inhibition and color-word Stroop tasks, respectively, and examined their interaction patterns in two different social cognitive processes: theory of mind and personal distress (a component of emotional empathy). Results showed that in both theory of mind and personal distress, the effect of inhibitory control was moderated by SOC. However, the pattern of SOC' s moderating effect was opposite in the two social cognitive domains. In theory of mind, inhibitory control was positively correlated with theory of mind only when SOC level was high; in personal distress, inhibitory control was positively correlated with personal distress only when SOC level was low.

We believe this pattern may be related to differences in the internal processing of the two social cognitive domains. In theory of mind reasoning, because individuals' own beliefs are completely different from others' beliefs, individuals need to represent two conflicting beliefs simultaneously. Here, individuals need to use inhibitory control to suppress interference from their own beliefs on others' beliefs (Symeonidou et al., 2016; Brown-Schmidt, 2009). However, before this, individuals should first distinguish and identify conflicts between self and other beliefs (the function of SOC). Only after this can inhibitory control function to suppress interference from one' s own beliefs to obtain others' beliefs; otherwise, individuals cannot determine which belief representation to suppress. Personal distress is a dimension of emotional empathy, reflecting the degree to which individuals personally experience others' negative emotions (Davis, 1983). Contrary to theory of mind reasoning, greater fusion between self and other emotions facilitates empathic resonance with others' emotions (Decety & Meyer, 2008; Decety, 2010). Therefore, lower levels of SOC facilitate fusion between self and other emotions, while higher levels of inhibitory control help us further suppress interference from our own different emotions on others' emotions. These results suggest that in social cognition, SOC may be a more critical factor than inhibitory control, as it can modulate inhibitory control' s effects according to different social cognitive contexts.

5. Summary and Outlook

In summary, SOC reflects the process by which our brains, in interactive situations, distinguish and regulate representations related to self and other according to different contexts. Existing research suggests that SOC may be a domain-general processing mechanism, existing not only in action imitation control but also in other higher-level social cognitive processes. Therefore, SOC is likely a common mechanism by which our brains process interactive information about self and other in social interaction. This makes it possible to improve other higher-level social cognitive abilities through motor-level SOC training. This is a novel research idea that not only helps us understand the processing mechanisms underlying social cognition but also provides an economical and effective practical approach for clinical rehabilitation of individuals with impaired social cognition (such as autism and alexithymia). However, current research on SOC remains limited. Based on existing literature, we believe the following issues require further investigation.

First, the internal working mechanism of SOC. Existing research indicates that SOC is related to the functions of aFMC and TPJ (Brass et al., 2005; Brass et al., 2009; Spengler et al., 2009). Some researchers believe these two brain regions have different functions in SOC: TPJ is mainly responsible for distinguishing between self- and other-related representations, that is, identifying the identity of self- and other-related representations (Decety & Lamm, 2007; Steinbeis, 2016), while aFMC receives processing signals from TPJ and regulates conflicts between self- and other-related representations (Brass et al., 2009; Spengler et al., 2009). Therefore, SOC processing may not be a unitary process but requires coordinated work across multiple brain regions. Future research should employ new experimental designs to examine functional connectivity between TPJ and aFMC to further explore SOC' s internal working mechanism.

Second, the temporal course of SOC and inhibitory control in social cognitive processing. Based on the respective functions of SOC and inhibitory control, theoretically SOC should operate before inhibitory control when understanding others' mental states. Because we must first distinguish between representations related to self and other and regulate conflicts between them before we can suppress interference from our own mental states on understanding others' mental states. Therefore, future research should use methods with higher temporal resolution to examine the temporal course of SOC and inhibitory control in social cognitive processing.

Third, the role of SOC in the development of social cognition. Although existing research shows that improved SOC capacity may enhance individuals' social cognitive abilities (de Guzman et al., 2016; Santiesteban et al., 2012), and SOC deficits can lead to social cognitive dysfunction (Castelli et al., 2002; Spengler et al., 2010), there is still a lack of empirical research directly examining the relationship between SOC and the development of social cognitive abilities. Meta-analytic research has found that the ability to inhibit Stroop interference (inhibitory control) develops rapidly between ages 5 and 11, slows between 11 and 14, and stabilizes after age 14 (mid-adolescence) (Romine & Reynolds, 2005). As is well known, adolescence is a critical period for the development of social interaction abilities, during which individuals' social cognitive abilities and corresponding brain functional structures undergo significant changes that play a key role in successful transition to adulthood (Blakemore & Mills, 2014; Kilford, Garrett, & Blakemore, 2016). As a key component of social cognitive processing, SOC may be related to the development of social cognition during adolescence. Therefore, future research needs to reveal the role of SOC in the development of social cognitive abilities at different adolescent stages and its neurobiological basis. Such research will not only help us understand the internal processing mechanisms of social cognition but also provide basic data support and guidance for training interventions for individuals with impaired social cognition such as autism and alexithymia. Alexithymia often co-occurs with autism (Oakley, Brewer, Bird, & Catmur, 2016), and recent research has found that guiding alexithymia patients to distinguish between self and other representations can improve their empathic responses to others (Saito, Yokoyama, & Ohira, 2016).

In conclusion, many questions about SOC require further investigation. Answering these questions will help deepen our understanding of the processing mechanisms and developmental patterns of social cognition, build a theoretical framework of social cognition centered on SOC, and support the design of economical and effective social cognition training programs.

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Note: Figure translations are in progress. See original paper for figures.