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Review

Self–other integration and distinction in schizophrenia: A theoretical analysis and a review of the evidence

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ABSTRACT

Difficulties in self–other processing lie at the core of schizophrenia and pose a problem for patients' daily social functioning. In the present selective review, we provide a framework for understanding self–other integration and distinction, and impairments herein in schizophrenia. For this purpose, we discuss classic motor prediction models in relation to mirror neuron functioning, theory of mind, mimicry, self-awareness, and self-agency phenomena. Importantly, we also discuss the role of more recent cognitive expectation models in these phenomena, and argue that these cognitive models form an essential contribution to our understanding of self–other integration and distinction. In doing so, we bring together different lines of research and connect findings from social psychology, affective neuropsychology, and psychiatry to further our understanding of when and how people integrate versus distinguish self and other, and how this goes wrong in schizophrenia patients.

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1. Introduction

In daily life people rarely act in social isolation. To ensure fluent and efficient social interaction people have to coordinate and *integrate* other people's thoughts, emotions, and behavioral intentions with their own (e.g., representing both one's own and another person's movements and grip when passing the salt). A prerequisite for doing this is the ability to *distinguish* between self and other. After all, when confusing self and other, one may project one's own intentions and emotions onto others, or take over the intentions and emotions of others. As such, it becomes challenging to develop a personal identity, regulate behavior, or hold one another responsible for certain behavior.

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As social beings, our brain seems to be designed to integrate our own and other people's intentions and emotions, as well as to distinguish between self and other. In most individuals integration and distinction of self and other is a well-balanced process, which occurs without effort or conscious attention. However, not everyone is blessed with the capacity to balance self–other distinction and integration. Specifically, schizophrenia patients often experience no control over their behavior and exhibit difficulties in distinguishing their own feelings, intentions, actions and their outcomes from those of others. Accordingly, recent literature has focused on self-disturbances as a possible explanation for both positive (i.e., extra thoughts, feelings, and behaviors not seen in healthy controls, e.g., delusions of control, auditory hallucinations, grandiosity, and delusions of reference) and negative symptoms of schizophrenia (Sass and Parnas, 2003; i.e., absence of normal thoughts, feelings, and behaviors, e.g., affective flattening, apathy, anhedonia, and avolition; Sass, 2014). Moreover, recent work shows that self–other disturbances (e.g., externalizing action control, aberrant self-awareness, and misunderstanding other people's intentions and emotions) are already present in early stages of the disease (Amminger et al., 2012; An et al., 2010; Parnas et al., 2011; Thompson et al., 2013, 2012) and might even be predictive of schizophrenia onset in symptomatic and genetically high risk individuals (Nelson et al., 2012; Parnas et al., 2014). Such findings indicate that self-disturbances lie at the core of the disease (Bleuler, 1911; Hemsley, 1998; Mishara et al., 2014; Sass and Parnas, 2003).

With regard to self–other processing, evidence shows that, although schizophrenia patients are able to *integrate* their own and others' (sometimes misinterpreted) behaviors and emotions (Abu-Akel and Shamay-Tsoory, 2013), they typically exhibit difficulties in *distinguishing* their own behaviors and emotions from those of others (Asai et al., 2011; Ford et al., 2007; Jardri et al., 2011, 2009). For example, some patients hear voices which they actually (sub vocally) produce themselves (Gould, 1948; Green and Kinsbourne, 1990; Van der Gaag, 2006), feel their limb movements being controlled by aliens (Frith, 2005), or think they caused events that are actually caused by someone else, as in delusions of reference (Synofzik et al., 2013a). In addition, a lack of self–other distinction may explain why patients get more easily distressed when confronted with the distress of others (i.e., emotional contagion; Montag et al., 2007).

Thus, abnormal processing of self and other is reflected in clinical symptoms, but also in an array of neural, social cognitive, and behavioral dysfunctions (Nelson et al., 2014). As such, it may be an important factor in explaining impaired social functioning in schizophrenia patients. Indeed, schizophrenia patients often struggle in social interactions (Patterson et al., 2001; Pinkham and Penn, 2006; Pinkham et al., 2007) and this is an outcome of the disease that patients find extremely difficult to cope with (Gorwood et al., 2013; Świtaj et al., 2012). The difficulties patients encounter in social interaction are usually explained by impairments in social cognition (Fett et al., 2011), for example in theory of mind (Brown et al., 2014). As social cognition is defined as 'the ability to construct representations of the relation between oneself and others and to use those representations flexibly to guide social behavior' (Adolphs, 2001, p. 231), self–other processing is a crucial aspect of social cognition, and is thus essential to social functioning.

Research on social cognition in schizophrenia has so far mainly focused on patients' ability to understand or *integrate* their own and others' intentions and emotions (e.g., emotion recognition, theory of mind). Surprisingly, little attention has been devoted to problems in self–other *distinction*. Distinguishing between the two concepts is complicated though, as integration and distinction of self and other are inextricably intertwined. That is, some processes underlying self–other integration may also affect self–other distinction, and vice versa. In this review article, we address the difficulties patients face when it comes to integrating as well as distinguishing self and other, and zoom in on mechanisms that may underlie self–other integration and distinction.

We can distinguish two major mechanistic models. So far, most work proposes that self–other processing crucially relies on the extent to which our motor control system is able to predict our own as well as others' actions and outcomes. However, people cannot always rely on motor predictions to integrate or distinguish self and other (i.e., when one has no clear prediction of one's own or others' actions, for example when actions may result in a variety of outcomes). In line with this notion, a second model has been proposed that takes into account, and emphasizes, the role of people's cognitions about their own and others' action-outcomes.

First, we will review research that was initially developed to map the perception and understanding of behaviors, intentions, and emotions of *others* (other-perspective). This research mainly focused on self–other integration, but we will show that it also provides insight into self–other distinction. Specifically, we will discuss the role of motor prediction as reflected in mirror neuron function and its implications for theory of mind and mimicry. Next, we will review research that was initially developed to map the perception and understanding of *one's own* behaviors, intentions, and emotions as distinct from those of others (self-perspective). Here, we specifically focus on the role of motor prediction in self-awareness and self-agency phenomena. In addition, we will discuss more recent research that suggests that self–other distinction does not always arise from motor prediction processes, but may also result from cognitive expectation processes that deal with information pertaining to one's own and others' behaviors, beliefs, and emotions. Fig. 1 shows a heuristic model depicting how the different motor prediction and cognitive expectation processes that will be discussed aid self–other integration and distinction.

Essentially, we propose that motor prediction and cognitive expectation processes are both affected in schizophrenia, and may each explain disturbances in self–other integration and distinction depending on the requirements of the task or context. Thus far, research on cognitive models of self–other integration and distinction evolved independently of research on motor prediction models, although recent studies have emerged investigating the interaction between cognitive and motor processes in self-awareness and agency attribution (Gentsch and Schütz-Bosbach, 2011; Moore et al., 2009; Sato, 2009; van der Weiden et al., 2013a). Furthermore, research on self–other *integration* mainly focused on the role of motor prediction in understanding *other people's* intentions and emotions (other-perspective), whereas research on self–other *distinction* mainly focused on the role of motor prediction in understanding *one's own* intentions and emotions (self-perspective). Our aim is twofold. First, we show that processes underlying self–other integration and self–other distinction are associated and may influence each other. Second, we show that in situations where motor prediction cannot inform self, other processing is crucially affected by cognitive expectations.

Our goal is not to provide a complete overview of the available studies. Rather, we give a selective review in order to bring together these different lines of research to further our understanding of when and how people integrate or distinguish self and other, and how this is impaired in schizophrenia patients. Finally, we will briefly discuss how self–other integration and distinction as resulting from motor prediction and cognitive expectation processes may affect social functioning in healthy controls and schizophrenia patients, and as such pave the way for promising and exciting directions for future research.

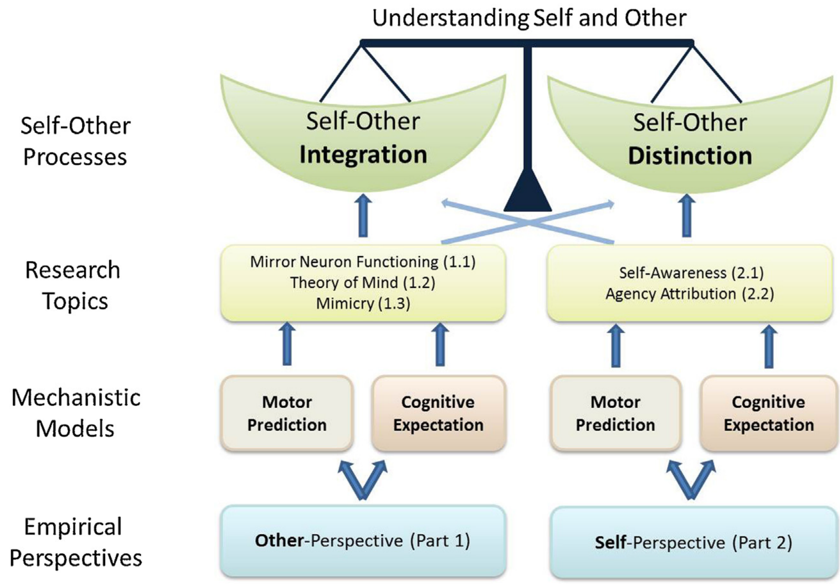

Fig. 1. This figure depicts how cognitive and motor processes aid self–other integration and self–other distinction.

2. Part 1: perception and understanding of others (other-perspective)

There is consistent and convincing evidence that the motor prediction system plays an important role in the representation of the behavior of others (i.e., other-perspective). Hence, motor prediction is often proposed as a model explaining self–other integration. We will integrate findings from studies on mirror neurons, theory of mind, and mimicry in healthy controls and schizophrenia patients, and explain them in the context of motor prediction. Specifically, we discuss how, at the neural level, mirror neurons not only facilitate people's understanding of others' behaviors and emotions, but also play a key role in distinguishing their own behaviors and emotions from those of others (see Section 2.1). In addition, we will discuss how theory of mind (Section 2.2) and mimicry (Section 2.3) may be affected by impairments in mirror neuron functioning. Also, in the latter two sections we will discuss the role of cognitive biases in theory of mind and mimicry in situations where motor predictions are less reliable (e.g., when actions can have multiple different consequences, or when it is unclear who performed the action).

2.1. Mirror neurons

Self–other integration. In the past decade, researchers have identified specific neurons that are involved in the processing of both one's own actions and those of others. This so-called mirror neuron network consists primarily of the inferior parietal lobe (guiding sensorimotor action and perception; Mattingley et al., 1998) and the ventral premotor cortex (involved in action planning and control; Hoshi and Tanji, 2006; Króliczak et al., 2008) plus the caudal part of the inferior frontal gyrus (associated with inhibition and attentional control; Hampshire et al., 2010), but may also include other areas depending on the characteristics of the observed or performed action (e.g., the primary auditory cortex for actions producing sounds; see Cattaneo and Rizzolatti, 2009; Molenberghs et al., 2012 for an overview). This network may be a fundamental feature of the brain, which enables implicit action understanding during interactions with the outside world (Gallese, 2003). The first studies on mirror neurons were conducted in macaque monkeys and showed that these neurons fired not only when macaques were grasping for an object themselves, but also when they observed another macaque or a human being grasping for an object (Gallese et al., 1996; Rizzolatti et al., 1996). This pre-reflective action simulation demonstrates a link between self and other (Gallese, 2003), and reflects the integration of one's own and others' actions.

Recently, similar findings have been demonstrated in humans (Cochin et al., 1999, 1998; Hari et al., 1998; Mukamel et al., 2010). However, in contrast to early conceptions of the mirror neuron system that have been extensively debated (Hickok and Hauser, 2010; Hickok, 2009; Steinhorst and Funke, 2014), recent studies suggest that mirror neurons do not simply activate an identical (i.e., mirroring) motor representation of the physical properties of the observed behavior. Rather, mirror neuron responsiveness is goal-dependent (Bonini et al., 2013; Ocampo and Kritikos, 2011), highlighting the central role of mirror neurons in higher level action understanding. That is, mirror neurons are equally responsive to a variety of actions (e.g., grasping or scooping) aimed at the same goal (e.g., eating), while mirror neurons are differentially activated for identical actions (e.g., grasping) with different goals (e.g., eating or placing). Furthermore, brain activation in the mirror neuron network is more pronounced when one observes another person's incomplete actions (grasping a cup in order to drink), rather than observing past action phases (Urgesi et al., 2010). Specifically, both during the planning of one's own actions and during the observation of others' actions, the same (mirror) neurons are activated in the premotor cortex. In other words, the observed ongoing action corresponds with an action that is familiar to the observer, enabling the observer to predict the actor's action-outcomes (see also Kilner et al., 2007).

Furthermore, mirror neurons do not only serve to understand or anticipate simple hand actions, but are also involved in understanding and anticipating more subtle emotional expressions (Carr et al., 2003; Iacoboni, 2009; Rizzolatti and Craighero, 2005). Specifically, overlapping brain areas (including the mirror neuron network and the limbic system) are activated when imitating or merely observing facial expressions (Carr et al., 2003; Molenberghs et al., 2012). Also, mirror neuron activity has been related to emotional empathy, indicating that mirror neurons play a key role in the understanding of other people's emotions (Kaplan and Iacoboni, 2006). Thus, the mirror neuron system is essential and fundamental for social interaction where people have to coordinate their behavior with others and anticipate and integrate the behavioral and emotional consequences of their own and others' actions (see also Sobhani et al., 2012). As such, the mirror neuron network has been primarily

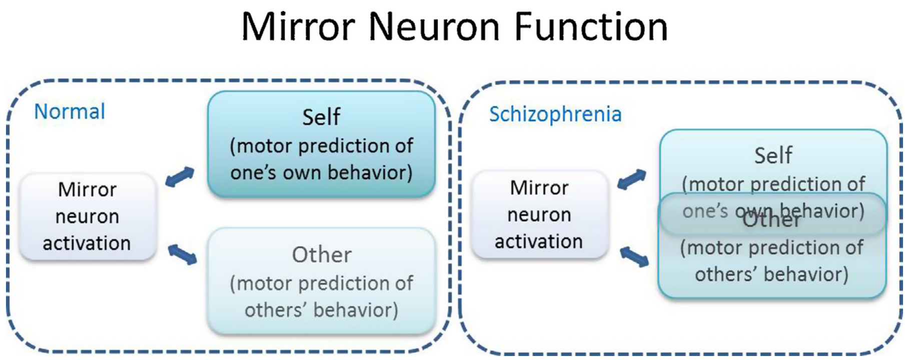

Fig. 2. This figure illustrates how mirror neuron function may be related to the prediction of one's own and other people's behavior. Specifically, mirror neuron activation in the motor cortex is usually higher when predicting one's own behavior compared with predicting other people's behavior. However, in schizophrenia, the prediction of other people's behavior results in the same amount of neural activation as predicting or planning one's own behavior. This may be a consequence of imprecise motor predictions, and could lead to the perception of illusory relations between one's own and other people's behavior.

associated with understanding and integrating people's own and other's behaviors and emotions.

Self–other distinction. The mirror neuron network is also crucially involved in distinguishing between one's own and others' behaviors or emotions. That is, a subset of mirror neurons in the hippocampus, parahippocampal gyrus, and entorhinal cortex show patterns of inhibition during action observation, while patterns of excitation are found during action performance. This differential pattern of activation has been proposed to be one of the fundamental mechanisms underlying self–other distinction (Mukamel et al., 2010). Mirror neurons thus allow one to simulate, anticipate, and understand the behavior of others (i.e., self–other integration), while at the same time they facilitate the distinction between one's own and others' actions (Veluw and Chance, 2014).

Mirror neuron function in schizophrenia. Studies in schizophrenia patients have shown that, similar to what happens in healthy people, the mirror neuron network is activated both in case of observing and performing an action (Jardri et al., 2011; McCormick et al., 2012; Thakkar et al., 2014). However, patients show abnormalities in the extent to which mirror neuron networks are activated when performing or observing actions. Specifically, compared with healthy controls, patients show overall reduced activity in the mirror neuron network (i.e., inferior parietal lobe, (pre)motor cortices, and inferior frontal gyrus), and this reduction has been related to negative symptoms and impaired social cognition (for a review: Mehta et al., 2014). This suggests that schizophrenia patients may be capable of understanding and anticipating (and thus integrating) the behavior of others, but possibly do this to a lesser extent than do healthy controls.

In addition, mirror neuron activity in schizophrenia patients does not differentiate between self-performed and other-performed actions (Jardri et al., 2011; McCormick et al., 2012; Thakkar et al., 2014), making it more difficult to distinguish between self and other. For example, in the study by Jardri and colleagues (2011) participants had to listen to their own recorded voice while mentally repeating the words (i.e., self-generated voice), and had to passively listen to unfamiliar voices (i.e., other-generated voice) and reverse-taped voices (i.e., control condition). Results revealed that when comparing self- versus other-generated voice, patients showed increased neural overlap in terms of space and amplitude in the medial frontal, medial parietal, and right middle temporal cortices as well as the right inferior parietal lobule. The increased overlap in the right inferior parietal lobule was due to increased activation in this area for self-produced voice compared with healthy controls, which may explain for example why some patients perceive their own voice as being externally generated (i.e., auditory hallucinations). In line with this notion, the level of activity in the right inferior parietal lobule positively correlated with positive symptoms.

Reduced activation and differentiation in the mirror neuron network may thus explain part of the negative and positive symptoms of schizophrenia, respectively. The lack of activation and/or self–other distinction at the mirror neuron level may further complicate the planning, monitoring, performance, and regulation of actions (see also part 2 of this review). Alternatively, as mirror neuron activation in the premotor cortex reflects the prediction and anticipation of the behavior of others, it may be that patients' impairments in motor prediction lead to less precise and thus more overlapping mirror neuron activation for their own and other's behavior. There may even be a bi-directional relationship between mirror neuron function and motor prediction (see Fig. 2). Future research may be able to identify the direction of causality in this respect.

2.2. Theory of mind

Current directions in social neuroscience suggest that mirror neuron functioning is crucial for an adequate theory of mind (Gallese and Goldman, 1998; Goldman, 2009, 1989), commonly defined as the understanding of other people's intentions and behavior (i.e., cognitive theory of mind) and other people's emotions (i.e., affective theory of mind; Abu-Akel and Shamay-Tsoory, 2013). Indeed, according to simulation theory, a basic recognition (Bora et al., 2005) and understanding of other people's behaviors and emotions can result from the motor *simulation* of these behaviors and emotions by the mirror neuron system (cf. simulation theory; Gallese and Goldman, 1998; Goldman, 2009, 1989). However, in complex social situations where the understanding of other people's behaviors and emotions requires an appreciation of social rules, motor simulation is not sufficient. These situations additionally require people to rely on cognitive *theories* or beliefs (cf., theory theory; Gopnik and Wellman, 1992; Perner and Howes, 1992). For example, people have to draw upon cognitive beliefs and theories in order to understand whether people in the direct social environment are laughing with or at you, or to understand why someone says to find something tasty while her face expresses disgust (e.g., lying, being polite, or being sarcastic), or why someone who just won the lottery is crying (i.e., tears of joy). The understanding of such complex intentions and emotions requires the integration of different (sometimes conflicting) messages that are difficult to understand when merely simulating a person's facial or bodily expressions.

Theory of mind in schizophrenia. So far, the evidence regarding schizophrenia patients' theory of mind is inconsistent. Some studies suggest that theory of mind is intact (Abu-Akel, 1999; Bora et al., 2006; Brüne, 2003; Pousa et al., 2008; Sarfati et al., 1999; Walston et al., 2000; Walter et al., 2009), while others indicate impairments in theory of mind in schizophrenia (Brüne, 2005; Derntl et al., 2009; Green et al., 2012; Haker and Rössler, 2009; Langdon et al., 2006a; Varcin et al., 2010) as well as in populations at high risk to develop schizophrenia (Chung et al., 2008; Marjoram et al., 2006). Based on the above, there are several possible explanations for the inconsistent findings. First, theory of mind may be differentially affected by patients' ability to *integrate* others' intentions and emotions, and their ability to *distinguish* others' intentions and emotions from their own. Second, as theory of mind is informed by motor simulation as well as cognitive belief processes that may each rely on different neural processes (Mahy et al., 2014), abnormalities in either one may be present in schizophrenia. Integration and distinction of self and other within both motor and cognitive processes will be described below.

Motor simulation and theory of mind in schizophrenia. According to simulation theory, the mere simulation of other people's behaviors and emotions is sufficient to arrive at a basic recognition and integration of those behaviors and emotions. In line with the notion that schizophrenia patients are able to simulate other people's behaviors and emotions (Jardri et al., 2011; McCormick et al., 2012; Thakkar et al., 2014), there is converging evidence that patients perform equally well as controls in attributing basic mental states (Brüne, 2003; Pousa et al., 2008; Shamay-Tsoory et al., 2007). That is, patients perform equally well as healthy controls on first order theory of mind tasks, which require a basic understanding of how someone else feels or what the other person is thinking.

However, because schizophrenia patients show a lack of differentiation in the simulation versus expression of behaviors and emotions (Jardri et al., 2011; McCormick et al., 2012; Thakkar et al., 2014), they may experience difficulty distinguishing the behaviors and emotions of others from their own. As a consequence, patients may mistake other people's intentions or emotions for their own (e.g., emotion contagion). Indeed, ample studies suggest that patients typically become more easily distressed when observing someone else in distress (Corbera et al., 2013; Decety and Lamm, 2011; McCormick et al., 2012; Montag et al., 2007; Ruby and Decety, 2004; Smith et al., 2015). Similarly, one may speculate that patients may also be more likely to experience others' intentions as their own, a phenomenon also referred to as goal contagion (Aarts et al., 2004). Such emotion (and possibly goal) contagion provides additional support for the notion that patients are able to form a basic understanding of others' intentions and emotions.

Cognitive beliefs and theory of mind in schizophrenia. It is only when situations get more complicated or demanding (and motor simulation becomes less informative) that schizophrenia patients struggle to understand other people's intentions, and especially emotions (Abu-Akel and Shamay-Tsoory, 2013; Corcoran et al., 1995; De Achával et al., 2010). In line with this notion, patients perform worse than healthy controls on more complex (second order) theory of mind tasks (Brüne, 2005), and this impairment has partly been explained by individual differences and task demands in IQ and working memory load (Brüne, 2003; Pousa et al., 2008), as well as processing speed (Brennan et al., 2014). Specifically, this latter study showed that while patients initially (within 70 ms) show reduced facial and emotional processing compared with controls, they do show enhanced later processing (Brennan et al., 2014). In dynamic social interactions, this slowed emotion processing may hinder emotion identification and integration (Derntl et al., 2009; Green et al., 2012; Haker and Rössler, 2009; Kring and Elis, 2013), as emotional expressions are very dynamic in nature and may rapidly change from one moment to another (Scherer, 2009).

Another consequence of patients' increased processing time is that they have less time to consider the social context. Perhaps as a consequence, patients have been shown to pay less attention to the social context when inferring mental states of others (Green et al., 2008), and may fail to perceive, or may misperceive causal relationships between the social context and other people's intentions, actions, or emotions (Green et al., 2010; Hemsley, 2005a,b). Such misperceptions may be further exacerbated by neural abnormalities (Bosia et al., 2012; Walter et al., 2009), diminished executive functioning (e.g., reduced working memory capacity, or difficulty filtering relevant from irrelevant information; Hemsley and Zawada, 1976; Lee and Park, 2005), and/or cognitive biases (Green et al., 2010; Langdon et al., 2006b). Indeed, patients are generally less accurate in identifying other people's mental states (e.g., happy or embarrassed) when embedded in a social context (e.g., a laughing person surrounded by other laughing people; Green et al., 2008; Kring and Campellone, 2012; Kring and Elis, 2013).

Patients' failure to take into account the social context may further explain why schizophrenia patients typically show difficulties understanding and integrating more *complex* intentions as communicated through lies or sarcasm (Derntl et al., 2009; Green et al., 2012), or as seen in faux pas tests that require people to detect and interpret violations of social rules (De Achával et al., 2010; Zhu et al., 2007). That is, in complex and dynamic situations where motor simulation is less informative, patients may develop and draw upon cognitive theories and beliefs about the mental states of others, devoid of social contextual nuances or based on a false, biased perception of the social context. Consequently, patients may experience particular problems with social functioning. Indeed, research indicates that theory of mind functioning in schizophrenia patients is an important contributor to social behavior in clinical settings (Brüne, 2005; Brüne et al., 2007), community functioning (Roncone et al., 2002), and interpersonal skills (Pinkham and Penn, 2006).

In order to gain more insight in how people arrive at a theory of mind, and to enhance our understanding of impairments herein, future research should appreciate that in line with abnormalities in mirror neuron activation, impairments in theory of mind may result from both reduced integration (e.g., misperception of others' intentions and emotions) and distinction (e.g., emotional contagion) of self and other, and these processes may sometimes be difficult to disentangle. For instance, patients may adopt misperceived emotions of others, reflecting difficulties in integration as well as distinction of self and other. Furthermore, future research should take into consideration whether theory of mind performance results primarily from motor simulation processes or from cognitive theories or beliefs, and how these processes interact. For example, it would be interesting to assess to what extent patients benefit from motor simulation when cognitively inferring the mental states of others (e.g., happy) by manipulating motor simulation ability (e.g., blocking the smiling muscles by biting a pen or wearing a mouthguard; Oberman et al., 2007; Rychlowska et al., 2014; Strack et al., 1988).

2.3. Mimicry

Mirror neuron activity does not only contribute to understanding other people's behaviors and emotions through motor simulation, it may even trigger the same behavioral or emotional expressions in the observer (Iacoboni, 2009). That is, people often subtly mimic (anticipated) behaviors and emotional expressions of others (Chartrand and Bargh, 1999; Frijda, 2010) and this functions as a 'social glue' by facilitating empathy (Maurer and Tindall, 1983; Stel and Vonk, 2010), helping behavior (Fischer-Lokou et al., 2011; Guéguen et al., 2011; Stel et al., 2008), feelings of closeness (Ashton-James et al., 2007; Lakin and Chartrand, 2003), and by reducing prejudice (Inzlicht et al., 2012).

Self–other integration and distinction. Similar to theory of mind, mimicry does not simply result from motor simulation, but is conditional to the social context. Specifically, people only mimic

Table 1
Summary of motor and cognitive processes involved in schizophrenia patients' impairments in the perception of other people's behaviors and emotions, and their implications for normal (in italic) versus abnormal (in bold) self–other integration and self–other distinction.

Model	Normal	Schizophrenia	Implications for self–other integration	Implications for self–other distinction
		MOTOR		
1. Mirror neurons	Activation when grasping and when seeing someone else grasping	Activation when grasping and when seeing someone else grasping	Intact ability to integrate self and other	
	Difference in activation for self-produced versus other-produced actions	No differentiation of self-produced and other-produced actions		**Less distinction of one's own and others' actions**
2. Theory of mind				
• Basic intentions	Understanding others' intentions	Understanding others' intentions	Normal identification and integration of others' intentions	*Possibly less distinction between one's own and others' intentions (e.g., goal contagion)*
• Basic emotions	Understanding others' emotions	Too much simulation	**Too much integration**	**Less distinction between one's own and others' emotions (e.g., emotion contagion)**
		COGNITIVE		
• Complex intentions	Understanding others' intentions	Impaired understanding of complex intentions (e.g., lies, sarcasm)	**Cognitive deficits affect identification and integration of intentions**	
• Complex emotions	Understanding others' emotions	Impaired understanding of emotions within a social context	**Cognitive deficits affect identification and integration of emotions**	
3. Mimicry	Mimicry of others' (anticipated) behaviors and emotions depending on the social context	Inappropriate mimicry	**Inappropriate bonding with others**	**Inappropriate distancing from others**

others when it serves an affiliative purpose (Bourgeois and Hess, 2008; Chartrand et al., 2005; Cheng and Chartrand, 2003; Hess and Fischer, 2013; Lakin et al., 2008). For example, one would mimic the fear of friends, but laugh at the fear of foes. Hence, mimicry, just as theory of mind, is crucially affected by cognitive theories or beliefs about the other person's personality (e.g., friendly versus unfriendly) or background (e.g., in-group versus out-group). In essence then, cognitive processes promote self–other integration (e.g., with friendly people), as well as self–other distinction (e.g., from unfriendly people), depending on the other person's identity and on the social context.

Mimicry in schizophrenia. As schizophrenia patients have more difficulty taking the context in consideration (Green et al., 2008; Hemsley, 2005a,b; Penn et al., 2002), they may be more likely to show abnormal mimicry behavior. Indeed, research suggests that schizophrenia patients show either excessive mimicry (Kring et al., 1999), or a lack of (or atypical) mimicry (Haker and Rössler, 2009; Park et al., 2008; Varcin et al., 2010). Such abnormal mimicry behavior reflects patients' difficulties in self–other integration as well as self–other distinction. However, little is known about the underlying mechanisms responsible for patients' abnormal mimicry behavior. There is some evidence that mimicry is negatively related to negative symptoms and poor social functioning (Haker and Rössler, 2009; Matthews et al., 2013; Park et al., 2008). However, it often remains unclear whether patients' abnormalities in mimicry behavior result from an inability to take the social context into account (resulting in excessive or atypical mimicry), from a decreased affiliative motivation of the mimicker (resulting in a lack of mimicry), or from cognitive theories or beliefs the mimicker has about the (anticipated) intentions or emotions of the mimickee (resulting in atypical mimicry, which may also be misinterpreted as a lack of mimicry when expressions identical to those expressed by the mimickee are expected but not seen). By taking these factors into account, future research may unravel the processes that contribute to patients' abnormalities in mimicry behavior.

3. Summary part 1

In summary (see also Table 1), we discussed how motor predictions and mirror neuron activation are involved in the anticipation and understanding of other people's behaviors and emotions (theory of mind). Crucially, based on the presence of mirror neuron activation, schizophrenia patients are able to integrate self and other. However, the lack of differentiation in activation for self-produced versus other-produced actions causes patients to integrate the intentions and emotions of others too much (reflected in abnormal theory of mind). We further showed that impairments at the motor level makes patients more dependent on less reliable cognitive theories and beliefs regarding the intentions and emotions of others. This not only impairs their understanding (i.e., integration) of others (i.e., theory of mind), but also their behavioral reactions (mimicry), which is detrimental for social functioning.

4. Part 2: perception and understanding of self (self-perspective)

In addition to processes that are involved in understanding *other* people's behavior, people also crucially rely on basic motor prediction processes that are associated with understanding their *own* behavior when distinguishing and integrating self and other. Actually, the very same notion that motor predictions are differentially associated with our own and others' actions and emotions inspired researchers to study the role of motor prediction processes in the awareness of our own actions (e.g., in terms of effectiveness, intensity, or duration; see Section 4.1) and attributions of self-agency (i.e., the explicit distinction between self and other as the cause of behavior; see Section 4.2). We will argue that, in addition to the role of motor predictions, cognitive expectations also play a crucial role in action-awareness and agency attributions. Furthermore, although the literature on these topics primarily focused on self–other distinction, we will also discuss implications for self–other integration.

4.1. Action awareness

According to the classic comparator model (Frith and Done, 2009; Frith, 2012), the motor system stores copies of each outflowing action signal (i.e., efference copies) that carry predictive information about the sensory consequences of the action. The motor system continuously compares these internally predicted outcomes with actual perceived outcomes and, if necessary, updates the predictions based on the received sensory feedback (see also Sober and Sabes, 2003). As such, the motor system plays a crucial role in the planning and regulation of one's own behavior. Although such action monitoring and regulation can take place without conscious awareness (Fourneret and Jeannerod, 1998), people usually become aware of their actions when distortions (i.e., a mismatch between prediction and sensory feedback) reach a certain threshold and become noticeable.

Action awareness in schizophrenia. Schizophrenia patients show impairments in the motor prediction processes that are involved in the monitoring and regulation of action (see Farrer and Franck, 2007 for an overview). Specifically, a recent study revealed that although schizophrenia patients show relatively normal brain activation during sensory feedback processing (but see Horan et al., 2012 for a more complex picture), they do show reduced sensorimotor activation preceding action execution, which reflects reduced motor prediction. Furthermore, in contrast to healthy controls, motor prediction and sensory feedback processing did not correlate in patients (Bender et al., 2012), indicating an interruption in the formation and updating of motor predictions. As a consequence, patients with schizophrenia have more difficulty learning associations between their actions and subsequent outcomes (Jones et al., 1991; Serra et al., 2001), and are typically less sensitive to behavioral distortions (Hommes et al., 2012; Malenka et al., 1982; Synofzik et al., 2010). For example, Synofzik and colleagues (2010) had participants perform out-of-sight pointing movements while observing false movement feedback (i.e., rotated to a certain extent). Compared with healthy controls, schizophrenia patients showed a larger threshold for detecting inconsistencies between their actual movement and the visual feedback (21.4° versus 13.1° distorted in angle). Interestingly, there is suggestive evidence that this impaired sensitivity is specific to certain psychotic symptoms. That is, impaired error detection has been related to paranoid-hallucinatory syndrome or formal thought disorders (Knoblich et al., 2004), and even to subclinical positive symptoms in unaffected siblings of patients with schizophrenia (Hommes et al., 2012).

Action awareness may also be affected by action monitoring in a more indirect manner. Specifically, evidence shows that motor predictions as well as cognitive expectations affect (a) the intensity of action awareness through a process called sensory attenuation, and (b) the temporal awareness of action events through a process called temporal binding. We will discuss how sensory attenuation and temporal binding contribute to the distinction, but also integration, of one's own and other's actions.

Sensory attenuation. Because people are able to predict quite precisely the sensory consequences of their own actions, they already experience to some extent what the action will feel like before actually performing the action. As a consequence, if the sensory consequences match one's internal predictions, the actual experience feels less intense (Roussel et al., 2013; Timm et al., 2014; Waszak et al., 2012). This so-called sensory attenuation is a fundamental phenomenon and is even witnessed in lower order species such as crickets (Poulet and Hedwig, 2002) and weak electric fish (Bell, 2001).

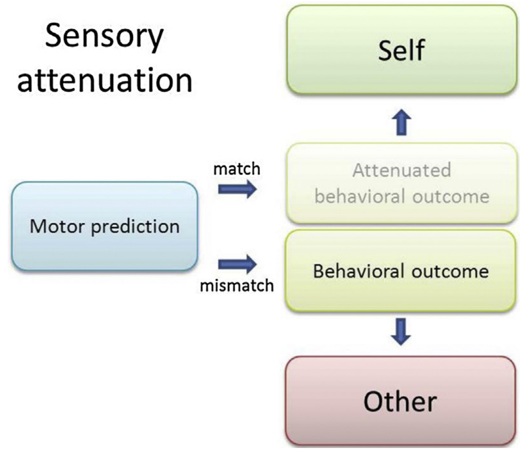

Fig. 3. This figure depicts the sensory attenuation of internally predicted behavioral outcomes, and how this sensory attenuation may inform self–other distinction.

The attenuation of predicted sensations is an essential mechanism that enables people to distinguish between actions and outcomes they produced themselves and actions and outcomes that are caused by others. That is, people are generally better at predicting the sensory consequences of their own actions as compared with those of other people's actions (see Fig. 3), causing self-produced sensations to feel less intense than other-produced sensations. This is, for example, why it feels much more intense when one is tickled by someone else, compared with when one tickles oneself (Blakemore et al., 1998).

Sensory attenuation for one's own versus others' actions resembles the differentiation in activation of one's own and others' actions in the mirror neuron network. This is not surprising as both sensory attenuation and mirror neuron activation rely on the precision of internal motor predictions. Also, there is suggestive evidence that sensory attenuation correlates with activation in the frontoparietal network, which is part of the mirror neuron network (Hughes and Waszak, 2011). Perhaps there is also a direct relationship between mirror neuron activation and sensory attenuation, such that increased activity in the mirror neuron network for one's own actions results in increased sensory attenuation for one's own actions, and hence an increased ability to distinguish one's own from others' actions.

Interestingly, recent research suggests that sensory attenuation is specifically attuned to distinguish self and other, as the attenuation of behavioral outcomes increases when interacting with other people (Weiss et al., 2011). Specifically, this research suggests that other people's action-outcomes are attenuated when produced upon one's own request compared with when they are produced by the other person individually. Thus, as long as one is at least partly responsible for an action, performed by either self or other, sensory attenuation is present. Crucially however, in such interactive social contexts, one's own actions performed upon the other's request also become more attenuated than usual, possibly due to an increased attention to one's own actions in order to prevent self–other confusion.

Sensory attenuation in schizophrenia. Schizophrenia patients are impaired in the motor prediction processes that are involved in the awareness of action, which significantly undermines their ability to distinguish between self and other. Specifically, recent electroencephalography (EEG) research has demonstrated that schizophrenia patients show impairments in the efference copies that are generated by the motor system (Bender et al., 2012; Ford et al., 2014, 2008). This manifests itself in less motor activation before action performance (i.e., less anticipation), and increased sensory activation (i.e., less attenuation) of action outcomes (Ford et al., 2014, 2008). Because of this lack of sensory attenuation, self-produced outcomes feel similar as other-produced outcomes, making it more difficult to distinguish one's own action–outcomes from those of others.

Indeed, in an inventive study by Blakemore and colleagues (2000), investigating sensory attenuation in schizophrenia, bipolar, and depressed patients, participants had to rate the intensity of a tactile stimulation on the palm of their left hand. This stimulation was either self-produced or externally induced. Healthy control subjects rated the self-produced tactile stimulation as less intense than externally produced stimulations (see also Blakemore et al., 1998). Interestingly, however, patients suffering from auditory hallucinations and/or passivity phenomena failed to notice a difference in perception between self-produced and externally induced stimulation. This decreased sensory attenuation crucially depended on the presence of these symptoms, and was independent of the diagnosis of schizophrenia or (bipolar) depression. Reduced tactile sensory attenuation has also been found in patients with paranoid symptoms (Bulot et al., 2007) and predominantly positive symptoms (Shergill et al., 2005). Furthermore, a single case-study showed reduced sensory attenuation in a patient with verbal auditory hallucinations and delusions of control (Jardri et al., 2009).

The deviant perception of externally generated touch may not only be related to psychotic symptoms, but may also play a role in patients' social functioning. That is, research in healthy subjects has shown that another person's touch increases compliance (Patterson et al., 1986; Willis and Hamm, 1980) and strengthens interpersonal relationships (Gallace and Spence, 2010). Future research may investigate whether patients' failure to differentiate between self-produced and other-produced touch makes them insensitive to such social influences.

Patients' failure to attenuate self-produced outcomes has also been replicated in the auditory (Ford and Mathalon, 2012; Ford et al., 2007; Heinks-Maldonado et al., 2007) and visual (Leube et al., 2010) domain. For example, Ford and colleagues (2007) examined the attenuation of speech in patients with schizophrenia. Attenuation was measured by suppression of the auditory event-related EEG potential N1. The results showed that whereas controls attenuated their own speech compared with recorded speech, schizophrenia patients did not. In addition to an increased awareness of aspects of experience that are normally tacit or implicit (Kapur et al., 2005; Sass and Parnas, 2003), the failure to differentiate between self-produced and externally produced sensory experiences may explain symptoms such as auditory hallucinations where patients experience self-produced speech as externally controlled (see also Nelson et al., 2014). Indeed, there is some evidence that patients with auditory hallucinations show less attenuation when hearing an alien voice compared with patients without auditory hallucinations (Heinks-Maldonado et al., 2007).

Temporal binding. Another way in which the internal prediction of action–outcomes affects action awareness is by changing the temporal perception of actions and outcomes. In order to make sense of our actions and the effects they have on the outside world, our brain has to integrate multiple sensory signals (i.e., multisensory integration). That is, as was also addressed in the classic comparator model of motor prediction, the brain integrates predictive action signals with signals accompanying observed action–outcomes, involving visual, auditive, tactile, and olfactory modalities. However, some signals take longer than others to reach the brain. For example, sound takes longer than vision, which is why we perceive lightning to precede thunder. Likewise, the visual perception of touching one's toe arrives sooner than the tactile perception on one's toe. To assure a coherent perception of events that happened at the same time, but reach the brain at different points in time, the brain waits a couple of milliseconds for the slowest signal to arrive before integrating the different signals (Vroomen and Keetels, 2010). This waiting period is also referred to as the 'temporal binding window' (Colonius and Diederich, 2004).

Although this temporal binding window is crucial for action monitoring, regulation, and awareness, it also creates noise and may potentially lead to illusory perceptions of coherence, i.e., perceiving events to co-occur that have nothing to do with each other. During early childhood, the temporal binding window, and hence the noise, decreases (Lewkowicz and Flom, 2014), and these developmental changes persist into adolescence (Hillock-Dunn and Wallace, 2012). The narrowing of the temporal binding window over time may result from an increased precision in the prediction of action–outcomes. That is, as we grow up, we learn which signals are likely to follow our actions (e.g., clapping our hands is bound to produce a distinct sound, visual pattern, and a certain sensation in both hands, but is not always followed by the light turning on), and in what timeframe. As a consequence, the brain may need less time to process and integrate these anticipated multisensory signals (Kail, 1991).

Indeed, learned associations between action events have been shown to crucially affect whether action events are perceived to occur at the same time, a phenomenon also referred to as 'temporal binding' (Buehner and Humphreys, 2009; Cravo et al., 2009; Haggard et al., 2002). Specifically, when having learned that a key press is always followed by a specific sound after a predictable delay (e.g., 100 ms), the action and delayed outcome are perceived as occurring closer together in time (Eagleman and Holcombe, 2002; Haggard et al., 2002). These prediction effects are so pervasive that when the sound is presented earlier than predicted (e.g., immediately after the key press), this creates the intriguing illusion of the sound preceding the action (Stetson et al., 2006). Furthermore, as people are better able to predict the outcomes of intentional compared to unintentional (e.g., externally triggered) actions, people generally perceive actions and outcomes as occurring closer together in time when performing intentional rather than unintentional actions (Haggard and Clark, 2003; Haggard et al., 2002). For this reason 'temporal binding' is also often referred to as 'intentional binding'. Thus, motor predictions regarding the co-occurrence of events shape the perception of time and coherence (see Fig. 4).

Temporal binding may be especially useful in social interactions where people perform actions and cause outcomes simultaneously or in close temporal proximity, such as when playing a duet on the piano (i.e., quatre-mains). Specifically, the precision with which we can generally predict the outcomes of our own actions narrows the window within which action–events are bound together in time. Hence, our own action–outcomes are more likely to match the precise internal predictions, and are thus more likely to fit the temporal binding window. Consequently, our own actions are more likely to be bound together in time with our own action–outcomes, rather than with action–outcomes of others that are less predictable. As such, the temporal perception of actions and resulting outcomes may crucially aid the distinction between our own and other's action–outcomes.

In addition, temporal binding may aid the integration, or understanding of other people's behavior. That is, because people generally have less precise predictions about the performance and consequences of other people's actions, the temporal window within which actions and outcomes of others' are bound together is wider. This enables people to perceive others' actions as coherent (Obhi and Hall, 2011a,b; Wohlschlager et al., 2003), without interfering with the monitoring and awareness of their own actions.

Temporal binding in schizophrenia. Only recently, studies addressed temporal binding of actions and outcomes in schizophrenia patients (Haggard et al., 2003; Voss et al., 2010). These studies suggest that, compared with controls, patients have a

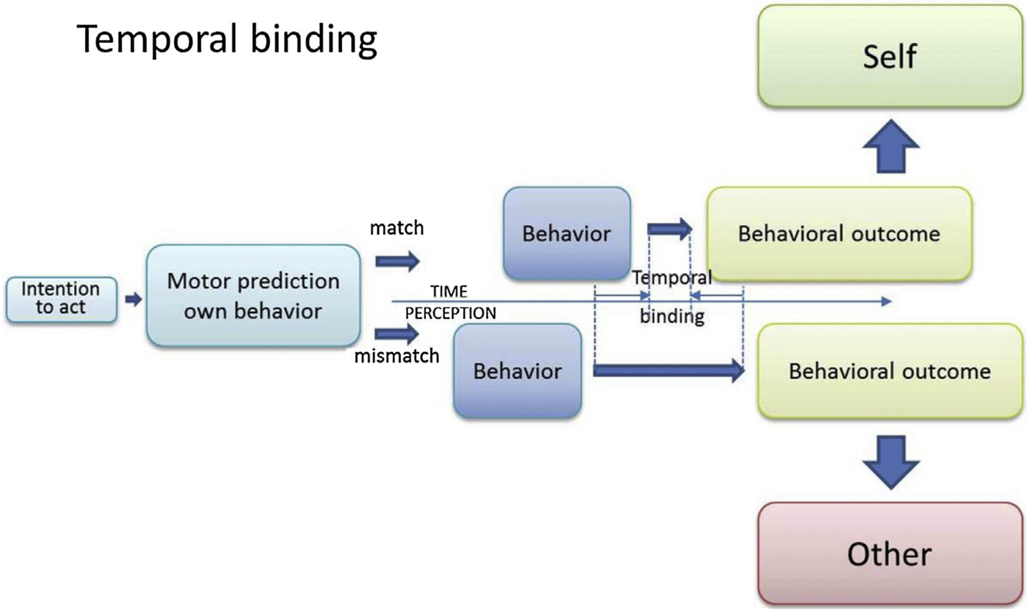

Fig. 4. This figure depicts the temporal binding between behavior and behavioral outcomes as a consequence of internal motor predictions, and how this temporal binding may inform self–other distinction.

greater temporal binding window (i.e., more noise) during which (multi)sensory signals are integrated. Consequently, patients are more likely to perceive other-produced outcomes as following from their own actions and vice versa. As such, patients' increased temporal binding window may crucially affect their temporal awareness of action, and as such their ability to integrate or distinguish self and other.

Additionally, a recent study indicated that, in contrast to controls, the temporal binding window of patients does not narrow as the probability of action–outcomes increases (from 50% to 75%; Voss et al., 2010). This insensitivity to the increased likelihood that a certain sensory signal results from a certain action may promote the integration of irrelevant sensory signals that occur after intentional action performance. As a consequence, schizophrenia patients may perceive illusory relations between their own actions, resulting action–outcomes, and other events (e.g., the doorbell, a voice on the radio, lightning), which may promote the formation of delusions and hallucinations (Corlett et al., 2007; Nathaniel-James and Frith, 2009).

Cognitive expectations and abnormalities in self-awareness in schizophrenia. There is recent evidence to suggest that both sensory attenuation and temporal binding do not only result from motor prediction processes, but can also arise from cognitive expectations about the source or outcome of an action (Desantis et al., 2012, 2011; Gentsch and Schütz-Bosbach, 2011; Moore et al., 2009). For example, when outcome expectations are induced by presenting the action–outcome before action performance (e.g., through priming), people show stronger sensory attenuation (Gentsch and Schütz-Bosbach, 2011), and stronger temporal binding between action and outcome (Moore et al., 2009; see Fig. 5).

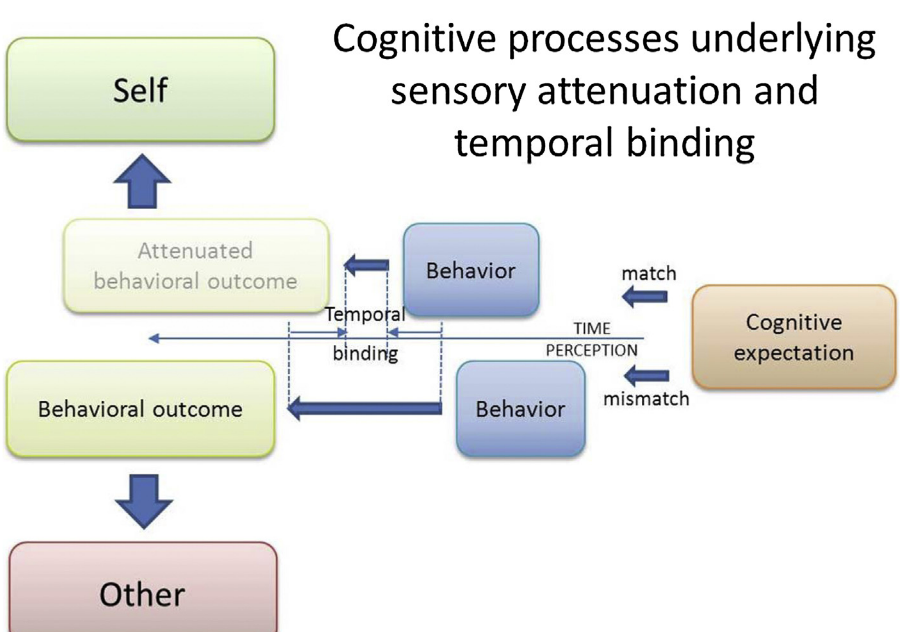

Fig. 5. This figure shows how self–other distinction arises from the attenuation and temporal binding of cognitively expected behavioral outcomes.

The influence of such cognitive expectation processes on the self-awareness of action has not yet been studied in schizophrenia. However, as patients often have false expectations or delusional beliefs about the potential sources and outcomes of their actions, it is likely that cognitive processes further complicate self-awareness of action in schizophrenia. For example, patients suffering from delusions of control may expect the outcomes of their actions to be caused by others, which would decrease sensory attenuation and temporal binding. As a consequence, they are more likely to perceive their action–outcomes as unrelated to their own action-performance, which would then reinforce their delusions of control. An intriguing possibility is that cognitive expectation processes are especially influential in schizophrenia, as impairments in motor predictions do not allow patients to differentiate between their own and others' actions. Hence, it is important to gain more insight in how cognitive expectation processes interact with motor prediction processes in producing sensory attenuation and temporal binding in healthy controls and schizophrenia patients. After all, cognitive expectations might be potential targets for cognitive therapy (Fig. 5).

4.2. Attributions of agency

As suggested above, impaired self-awareness of actions may lead patients to attribute self-caused outcomes to the actions of other people, or to attribute outcomes caused by others to their own actions. This is detrimental for daily (social) functioning, as correct attribution of agency is essential to self-perception, social interaction, and our society in general (Daprati et al., 1997; Frith, 2013; Hirstein and Sifferd, 2011; Lind et al., 1990; Moretto et al., 2011). In this section we will discuss more direct empirical evidence of aberrant agency attributions in schizophrenia. Again, we will disentangle the role and implications of motor prediction processes and cognitive expectation processes. Basically, we will argue that the involvement of cognitive processes increases when motor processes are uninformative or unreliable. Furthermore, how cognitive processes affect agency attribution might be dependent on the symptom profile of a patient.

Agency attribution from a motor perspective. As became apparent in the last section, the motor system may play an important role in the feeling of causing our own actions and resulting outcomes (i.e., feeling of agency). First, feelings of agency may be informed by the awareness of our own actions (e.g., sensory attenuation and temporal binding). However, when and how action awareness affects attributions of agency is still unclear (Dewey and Knoblich, 2014; Ebert and Wegner, 2010; Frith, 2013; Synofzik et al., 2013b; van der Weiden et al., 2013a). For example, when one's conversation partner speaks in a soft voice (i.e., resembling sensory attenuation), one does not necessarily experience agency over her voice. Second, motor predictions may affect agency attributions in a more direct way. That is, because people can generally quite precisely predict the outcomes of their own actions, while they are less accurate in predicting the actions and outcomes of other people, people typically attribute agency to themselves when outcomes match their predictions and to others when outcomes mismatch their predictions (see left side of Fig. 6).

Agency attribution from a motor perspective in schizophrenia. As referred to previously, there is evidence to suggest that in patients with schizophrenia motor prediction is distorted (e.g., due to impaired efference copies; Bender et al., 2012; Ford et al., 2014, 2008). As a result, it is more difficult to determine whether a sensory event matches the internal prediction, and hence, to attribute action–outcomes to either self or other. This impairment is reflected in several psychotic symptoms. That is, patients may be inclined to attribute agency over self-produced outcomes to others (under-attributing agency to self), as in auditory hallucinations

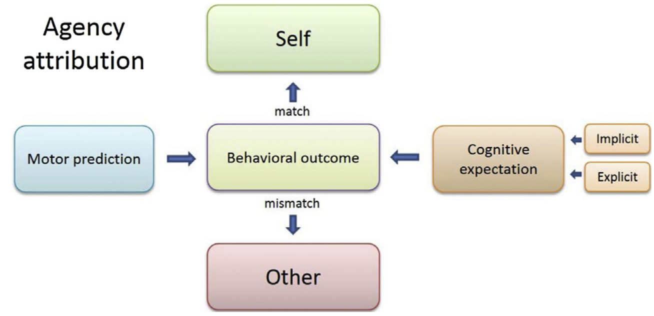

Fig. 6. This figure depicts the contribution of motor prediction and implicit as well as explicit cognitive expectation processes to the attribution of agency.

(Gould, 1948; Green and Kinsbourne, 1990; Van der Gaag, 2006), or delusions of alien control (Frith, 2005). Conversely, patients may attribute outcomes that were generated by others to themselves (over-attributing agency to self), such as manifested in grandiose delusions or delusions of reference (Maeda et al., 2012). Indeed, although there is still relatively little research on explicit agency attributions in schizophrenia, both types of misattributions have been observed in schizophrenia patients (Hur et al., 2014; Johns et al., 2001; Park and Nasrallah, 2014; Schimansky et al., 2010), and even in people at-risk to develop the disorder (Hauser et al., 2011; Johns et al., 2010; Thompson et al., 2013).

Over-attributions of agency in schizophrenia. In a recent study, participants' experiences of agency were measured while feedback of their cursor movements toward an asterisk in the left or right upper corner of the computer screen was manipulated. Participants either saw real feedback of their movement, or false feedback (i.e., cursor still moved toward the asterisk, but deviated slightly in onset, pace, and path from their current movement). Participants were led to believe that on several trials they would not see their own movement, but the movement of the experimenter who performed the task in another room. At the end of each trial, participants indicated whether they had seen their own or the experimenter's movement. Results showed that, compared with healthy controls, schizophrenia patients more often identified the false feedback movements as self-generated (Schimansky et al., 2010).

Over-attributions of agency are often explained to result from too much noise in motor predictions. That is, because of impairments in the internal prediction of action-outcomes, schizophrenia patients may perceive outcomes that are in fact slightly deviant (e.g., spatially or temporally) as matching their internal predictions (Metcalfe et al., 2012). This perception may result from patients' increased temporal binding window, facilitating the multisensory integration of actions and relevant as well as irrelevant external events. As a consequence, patients may learn associations between their actions and outcomes that actually occur beyond their control (Corlett et al., 2010). This flexibility in schizophrenia patients' representation of their own behavior thus leaves room for over-attributions of agency.

Over-attributions of external events to the self as a result of an increased temporal binding window is not limited to over-attributions of agency over action–outcomes, but also extends to false attributions of body ownership in schizophrenia patients (Peled et al., 2000; Thakkar et al., 2011), and individuals with schizotypal experiences (Asai et al., 2011). That is, the integration of synchronous multisensory input, i.e., tactile perception of touch on one's own hand and visual perception of touch on a rubber hand is known to create the illusion that the rubber hand is one's own (Botvinick and Cohen, 1998; Suzuki et al., 2013). Compared with healthy controls, schizophrenia patients report stronger rubber hand illusions. This supports the notion that patients have a more flexible representation of their 'self', resulting in a reduced ability to distinguish self and other and a tendency to over-attribute external events or objects (such as a rubber hand) to themselves.

In line with clinical observations, there is empirical support that over-attributions of agency are specifically related to delusions of control (Hauser et al., 2011), but not with a wider spectrum of first-rank symptoms (i.e., passivity symptoms such as thought insertion, depersonalization and delusions of alien control; Schimansky et al., 2010).

Under-attributions of agency in schizophrenia. In contrast to over-attributing agency to oneself, there is also convincing evidence that, compared with controls, schizophrenia patients tend to under-attribute agency over outcomes to themselves (Johns et al., 2001; Renes et al., 2013). In other words, schizophrenia patients typically fail to recognize their action–outcomes as their own. For instance, in one study participants had to read sentences aloud while they simultaneously heard the sentences in their own voice, their own voice distorted (i.e., increased by 3 semi-tones), or another person's voice. When asked to indicate whether they heard their own voice (normal or distorted) or another person's voice, they were more inclined to attribute their own voice to the other person as compared with healthy individuals (Johns et al., 2001).

A possible explanation for finding both over- and under-attribution of self-agency in patients is a crucial difference in the tasks used in the different studies. In studies where patients tend to under-attribute agency to themselves the deviations or distortions from their own, self-produced actions are clearly noticeable and can be consciously reflected upon. In contrast, studies providing evidence of over-attribution use subtle deviations from people's own, self-produced actions that may still be perceived to match patients' noisy internal predictions. Cognitive reflections resulting from action awareness thus seem to play a key role in the attribution of self-agency. Hence, in order to fully understand when patients over- versus under-attribute agency to themselves, it is important to also consider the cognitive processes underlying experiences of agency.

Agency attribution from a cognitive perspective. In situations where motor prediction of the outcome of our action is uninformative or less reliable, cognitive inferences of agency are especially influential (Moore et al., 2009; Synofzik et al., 2008; Vosgerau and Synofzik, 2012). This is the case when our actions may produce a number of different consequences or when there are other agents who also perform actions that may produce multiple outcomes. For example, when you make a funny face and people start laughing, you may have predicted their laughter, but that does not mean you were the one that made them laugh. They may as well be laughing because someone is imitating you in a funny way. In such situations people have to rely on cognitive inferential processes to arrive at the experience that they (rather than someone else) were the cause of their own actions and resulting outcomes. Hence, patients who have impairments in motor prediction processes are probably chronically more dependent on such cognitive inferential processes (Horan et al., 2012; Metcalfe et al., 2012). As a result, they are more susceptible to cognitive biases and beliefs that may direct their agency experiences toward over- or under-attribution (Bentall et al., 1994; Martin and Penn, 2002; Thompson et al., 2013).

Explicit cognitive expectations. According to the cognitive inferential account to self-agency people typically infer that they caused a behavioral outcome when this outcome matches the outcome they had in mind (Wegner, 2002; see right part of Fig. 6). For example, if you were craving pasta all day and you come home to discover that your partner made pasta for dinner, you may feel that you somehow, magically, caused your partner to do so. In some situations people have a certain outcome in mind because they have an explicit goal to reach a certain outcome (e.g., eating pasta). Yet, most (especially social) behavior is not planned or intentional (Bargh and Morsella, 2008; Custers and Aarts, 2010; Fourneret and Jeannerod, 1998; Moskowitz, 2002; Soon et al., 2008). Still, people can experience self-agency over this 'unintentional' behavior and its consequences. So, how do experiences of self-agency over behavioral outcomes unfold in ambiguous (social) situations characterized by the absence of an explicit goal and associated motor predictions?

Implicit cognitive expectations. Recent studies showed that the inferential process underlying experiences of self-agency is not only susceptible to goal-directed processes, but also to subtle environmental cues that carry information about the outcomes of our actions outside of conscious awareness. In experimental tasks, such subtle outcome information is presented with an intensity that is too low to reach the threshold of conscious awareness (i.e., subliminal priming). One commonly used experimental task aimed at assessing cognitive agency inferences is the so-called 'wheel of fortune task' (Aarts et al., 2005; Belayachi and Van der Linden, 2010; Dannenberg et al., 2012; Renes et al., 2015; van der Weiden et al., 2013b). This task requires participants to move a gray square along a rectangular path consisting of eight white squares in counterclockwise direction. At the same time the computer moves another gray square at the same speed in the opposite direction. After some time, a stop cue appears, and participants have to stop the movement of the squares by pressing a stop button. The moment that they press the stop button ostensibly determines on what locations the gray squares will stop. In actuality, participants have no actual control (i.e., the computer always determines the squares' stop locations), rendering internal motor predictions unreliable and uninformative for attributing agency. Crucially, participants only get to see one of the squares' stop locations, presented in black to make the cause of this outcome ambiguous. After each trial, participants rate the extent to which they feel that they caused their square to stop on the presented location, as a measure of experienced self-agency. To manipulate their experiences of self-agency, participants are either assigned the goal to stop their square on a specific location, or are briefly primed with the location instead. The presented stop location either matches or mismatches this goal or prime.

Indeed, experienced self-agency is generally increased when an action–outcome matches one's explicit goal, and decreased when an action–outcome mismatches one's explicit goal (Aarts et al., 2005; van der Weiden et al., 2013b). Similarly, experienced self-agency is generally enhanced when an action-outcome has been primed in advance, even though people do not consciously detect the outcome primes (Aarts et al., 2005; Belayachi and Van der Linden, 2010; Sato, 2009; van der Weiden et al., 2013b). Thus, cognitive expectations underlying agency experiences can be shaped by explicit goals as well as implicit primes, albeit through different mechanisms and with different consequences (van der Weiden et al., 2013b).

Cognitive agency processing in schizophrenia. Surprisingly, in patients with schizophrenia, these cognitive inferential processes have not yet received much attention. Only recently, we conducted a study on the influence of both implicit and explicit outcome cues (i.e., goals and primes) on experiences of self-agency in healthy controls and schizophrenia patients (Renes et al., 2013). In this study, participants performed the 'wheel of fortune task' as described above.

Results showed that both healthy controls and schizophrenia patients experienced more self-agency over outcomes that matched, rather than mismatched the goals (see also Voss et al., 2010), although patients overall experienced less self-agency (i.e., under-attribution of agency). Moreover, in contrast to controls, the implicit outcome primes had no effect on experiences of self-agency in patients. Importantly, in line with the notion that fast bottom-up visual processing is intact in schizophrenia (Del Cul

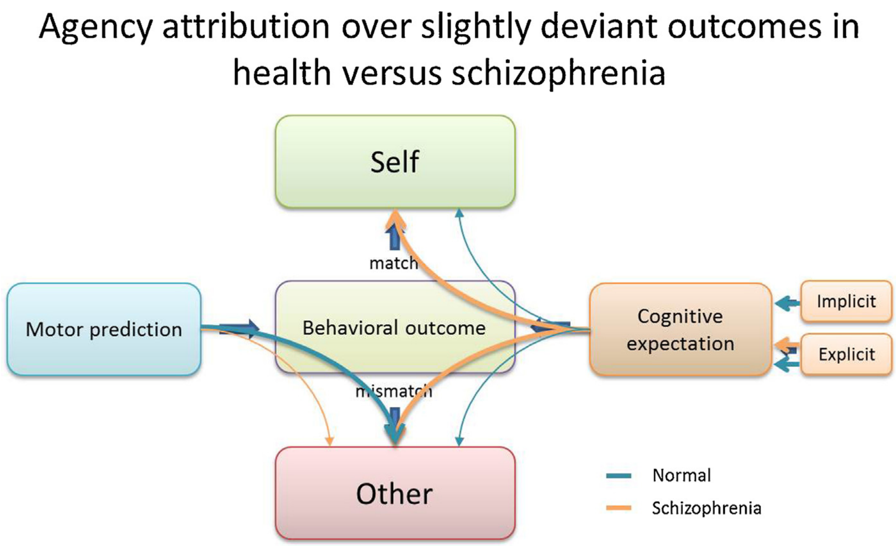

Fig. 7. This figure illustrates how schizophrenia patients deviate from healthy controls when attributing agency over outcomes that are slightly deviant from internal motor predictions. The blue arrow shows how errors in motor prediction (e.g., temporal or spatial deviations) weigh stronger than cognitive inferences and normally lead to the attribution of agency to others. The orange arrow depicts how schizophrenia patients' insensitivity to motor prediction errors causes them to attribute agency based on cognitive expectations. Thus, when outcomes are slightly deviant but still match cognitive expectations (e.g., when hearing one's own voice a few milliseconds later), patients will over-attribute agency to themselves. However, when outcomes are not as expected (i.e., in the absence of an explicit expectation or when outcomes deviate to a large extent from one's expectation, e.g., when hearing a voice that is clearly and qualitatively different from one's own), patients tend to attribute agency to others, and as such under-attribute agency to themselves. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

et al., 2006), we recently replicated and extended this finding by showing that schizophrenia patients were unable to use implicit outcome information when inferring self-agency, regardless of their intact ability to visually process and attend to the implicit outcome primes (Renes et al., 2015).

Thus, in the presence of others and in the absence of an explicit goal to reach a specific outcome, patients grope in the dark and are likely to under-attribute agency to themselves. Patients' inability to use subtle, implicit cues that convey information on what outcome to expect when performing an action may be particularly problematic in social interaction where information is usually implicitly available (e.g., in non-verbal communication). These findings thus converge with patients' general inability to take the social context into account (Green et al., 2008; Hemsley, 2005a,b; Penn et al., 2002).

The weighing of motor predictions and cognitive expectations in schizophrenia. In contrast to implicit agency processing, patients showed no impairments in experiencing self-agency over outcomes that matched their explicitly set goals in our study. However, explicit agency processing may under certain circumstances bias patients to over- or under-attribute agency to themselves (Maeda et al., 2012; Renes et al., 2013; Schimansky et al., 2010). That is, whereas errors in motor prediction (e.g., temporal or spatial deviations) usually weigh stronger than cognitive inferences (Moore et al., 2009; Synofzik et al., 2009) and normally lead to the attribution of agency to others (see blue arrow in Fig. 7), schizophrenia patients' insensitivity to motor prediction errors causes them to attribute agency based on their cognitive outcome expectations (e.g., based on goal achievement; orange arrow in Fig. 7).

Thus, when outcomes are slightly deviant but still match their cognitive expectations (e.g., when hearing one's own voice a few milliseconds later), patients will over-attribute agency to themselves. Indeed, in the studies discussed earlier that showed over-attributions of agency in schizophrenia, outcomes may have been deviant (e.g., movement feedback of the cursor differed in onset, pace, or path), but were always congruent with the goal they were pursuing (e.g., the cursor reached the intended location). Yet, when outcomes are not as expected (i.e., in the absence of an explicit expectation or when outcomes deviate to a large extent from one's expectation, e.g., when hearing a voice that is clearly and qualitatively different from one's own), patients tend to attribute agency to others, and as such under-attribute agency to themselves.

Cognitive outcome expectations, and hence agency attributions, may be crucially modulated by cognitive biases and personal beliefs (Aarts and van den Bos, 2011; Desantis et al., 2011; Fitch, 1970). Since patients excessively rely on cognitive inferences, they may be even more susceptible to such cognitive biases and beliefs. For instance, as a result of impaired motor predictions, patients may develop the belief that their actions bare no relation to the events they observe in their environment whatsoever (i.e., defeatist beliefs; see van der Weiden et al., 2011). Similarly, some patients may actually develop the belief that they can cause virtually any external event (i.e., grandiose beliefs). Such beliefs may bias agency attributions toward under and over attributions of agency respectively, thereby further reinforcing prior beliefs.

This way, patients' impairments in processing implicitly available information may not only underlie attributional biases, but may also reinforce their bias against disconfirmatory evidence (Garety and Freeman, 1999; Penn et al., 2008; Woodward et al., 2006). In line with this notion, recent research showed that patients who predominantly had positive symptoms were more likely to *over-attribute* agency over deviant yet goal-congruent outcomes to themselves (Maeda et al., 2013, 2012), whereas patients who predominantly had negative symptoms were more likely to *under-attribute* agency over deviant yet goal-congruent outcomes to themselves (Maeda et al., 2013). Perhaps patients with predominantly positive symptoms have higher expectations of reaching their goals than do patients with predominantly negative symptoms. Such expectations may also bias patients with predominantly positive symptoms toward under-attributions of agency when outcomes are goal-incongruent (i.e., when hearing voices with negative content). Given the crucial role of beliefs in agency attributions in schizophrenia, it would be interesting for future research to test the effect of therapies aimed at reducing defeatist beliefs in

Table 2
Summary of motor and cognitive processes involved in schizophrenia patients' impairments in self-perception, and their implications for normal (in italic) versus abnormal (in bold) self–other integration and self–other distinction.

Model	Normal	Schizophrenia	Implications for self–other integration	Implications for self–other distinction
MOTOR				
1. Action awareness				
• Sensory attenuation	Attenuation of self-produced outcomes	No attenuation of self-produced outcomes		**Less self–other distinction**
• Temporal binding	Integration of predicted multisensory signals that occur in close temporal proximity	Integration of a variety of multisensory signals that do not belong together due to increased binding window	**Too much integration of internal and external signals**	**Less self–other distinction**
2. Agency attribution				
• Motor prediction	Mispredictions lead to less experienced self-agency	Mispredictions do not lower experienced self-agency		**Over-attribution of agency to self**
COGNITIVE				
• Implicit cues	Matching outcome representations enhance experienced self-agency	Matching outcome representations do not enhance experienced self-agency		**Under-attribution of agency to self**
• Goal attainment	Enhances experienced self-agency	Enhances experienced self-agency		*Normal attribution of agency to self*

patients with symptoms of under-attribution (i.e., delusions of control, thought broadcasting, thought insertion, thought withdrawal, or auditory (verbal) hallucinations).

In conclusion, when investigating agency attribution in schizophrenia patients, it is essential to take into account motor as well as cognitive processes, implicitly as well as explicitly available outcome information, and cognitive biases and beliefs that may or may not be expressed in schizophrenia symptoms. These factors may jointly or independently drive patients to either over- or under-attribute agency to themselves, and as such distinguish self from others.

5. Summary part 2

To summarize (see also Table 2), in part 2 we showed how motor predictions and cognitive expectations aid the distinction of self and other as the cause of behavior, as reflected in self-awareness and attributions of agency. Specifically, as a consequence of reliable internal motor predictions, one's own behavioral outcomes are generally perceived as less intense (i.e., sensory attenuation; Blakemore et al., 1998; Roussel et al., 2013) and as temporally closer to the performance of action (i.e., temporal binding; Haggard et al., 2003; Moore and Haggard, 2008). As such, motor predictions aid self–other distinction, as is also supported by the role of motor predictions in attributions of agency (Sato, 2009; van der Weiden et al., 2011). Because schizophrenia patients have impaired motor predictions (Farrer and Franck, 2007), they typically struggle to distinguish self from other (Blakemore et al., 2000; Johns et al., 2001; Renes et al., 2013). Importantly, when motor predictions are less reliable, as is the case in schizophrenia, the distinction between self and other is crucially influenced by cognitive expectations about the outcomes of our actions (Aarts et al., 2005; van der Weiden et al., 2013a,b). These cognitive expectations are biased by patients' symptoms and may lead to over- as well as under-attributions of agency (Maeda et al., 2013, 2012). As such, cognitive expectation processes are potentially interesting targets for cognitive therapy with the aim of improving self–other distinction and social functioning.

6. Concluding remarks

As follows from the theoretical models and empirical studies reviewed above, self–other distinction is the product of motor prediction and cognitive processes that are involved in the understanding of other people's behaviors and emotions (other-perspective) as well as the understanding of one's own behaviors and emotions (self-perspective). Fig. 8 shows an integrative model of the processes involved in self–other distinction.

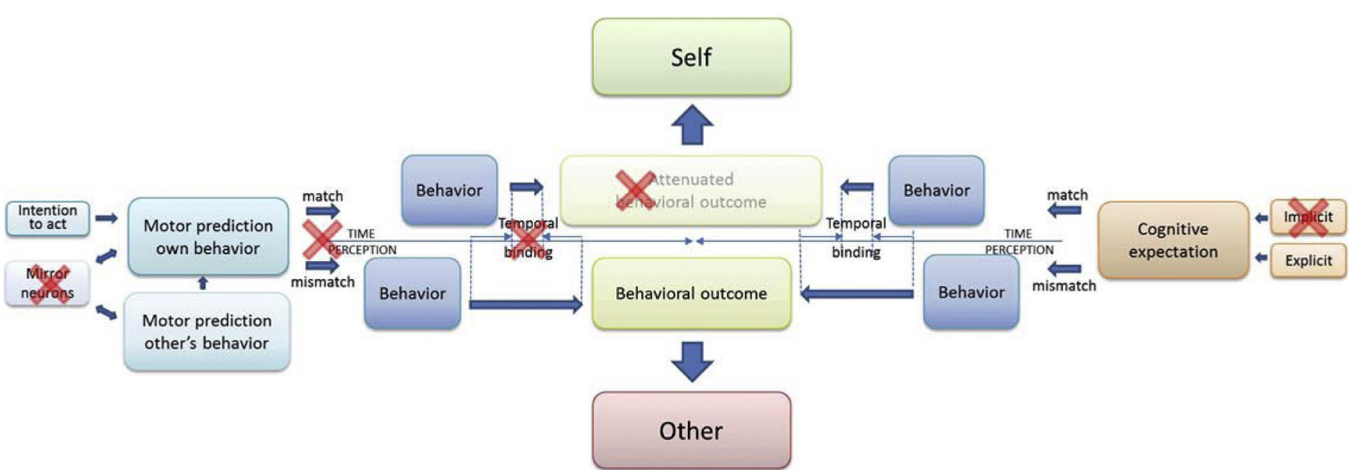

Fig. 8. This integrative model illustrates how the distinction between self (upper part of model) and other (lower part of model) results from both motor prediction (left part of the model) and cognitive expectation (right part of the model) processes. The red crosses indicate impairments in schizophrenia. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

So far, research on self–other processing in schizophrenia neglected the notion that self–other integration and self–other distinction are inextricably intertwined, and this has usually not been recognized in experimental set-ups. Yet, as we argued, both integration and distinction play a key role in the development of psychotic symptoms and impairments in social functioning. In the present review, we discussed how models that were developed to map either self-perception (self-perspective) or the perception of others (other-perspective) explain self–other integration as well as self–other distinction.

6.1. Self–other integration

Motor. Classic motor prediction models that took center stage in most research on self–other processing account for patients' *ability* to integrate self and other. Specifically, mirror neurons are active for both self-produced and other-produced actions. This enables patients to understand *basic* intentions of others. However, patients tend to integrate the behaviors and emotions of others too much, due to increased motor simulation (reflected in abnormal first order ToM) and an increased temporal binding window (reflected in abnormal action awareness).

Cognitive. Importantly, we further showed how cognitive biases and demands (e.g., processing speed) cause patients to incorrectly integrate and hence misunderstand more *complex* and dynamic intentions and emotions (reflected in abnormal second order ToM). As such, we have provided a framework for understanding schizophrenia patients' impairments in theory of mind, which have been a topic of debate in the literature. In addition, we showed that patients' incorrect integration causes them to inappropriately respond to and bond with others (reflected in abnormal mimicry).

6.2. Self–other distinction

Motor. Although patients show mirror neuron activation for their own as well as others' actions, the amount of activation does not differentiate between their own and others' actions, resulting in a lack of distinction between their own and others' behaviors and emotions. This is reflected in patients' abnormal action awareness (i.e., decreased sensory attenuation and an increased temporal binding window) and over-attributions of agency.

Cognitive. We also introduced a new perspective on abnormal agency attribution, by explaining how impairments in both motor prediction (i.e., reduced awareness of subtle distortions) and cognitive processes (i.e., biased expectations) may lead to over versus under-attribution of agency, as apparent in specific psychotic symptoms.

In some areas integration and distinction are more difficult to disentangle based on the existing literature. For example, patients' abnormalities in theory of mind (e.g., emotion contagion) may result from increased neural activation in response to others' intentions or emotions, or from decreased down-regulation of others' intentions or emotions relative to their own intentions or emotions (Decety and Meyer, 2008). Similarly, in temporal binding, increased integration of self and other (and hence a reduced ability to differentiate between one's own and others' actions) may follow from impaired motor prediction (reduced distinction) as well as from too much simulation of others' actions (increased integration). Also with regard to mimicry, it remains an open question whether patients' reduced mimicry reflects an absence of mimicry (i.e., reduced integration or increased distinction), or merely incorrect mimicry (and thus incorrect integration). Future research may shed more light on how integration and distinction processes interact to shape people's perception and understanding of their own and others' behaviors and emotions.

To conclude, there is more to self–other processing than meets the eye. Hence, in order to enhance our understanding of self–other processing and impairments herein in schizophrenia, future research should take into account the complexity of social perception and behavior. Specifically, we argue that disentangling self–other integration and distinction, as well as motor prediction and cognitive expectation processes, will crucially advance current research on social cognition and social functioning in both healthy controls and schizophrenia patients, and may serve to improve patients' understanding, coordination, and attribution of behavior, and ultimately, their quality of social life.

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