Schizophrenia Bulletin vol. 43 no. 4 pp. 745–753, 2017
doi:10.1093/schbul/sbw220
Advance Access publication March 3, 2017

Embodiment and Schizophrenia: A Review of Implications and Applications

Wolfgang Tschacher*[,1], Anne Giersch[2], and Karl Friston[3]

[1]Universitätsklinik für Psychiatrie und Psychotherapie, Universität Bern, Bolligenstrasse 111, 3060 Bern, Schweiz; [2]INSERM U1114, FMTS, Departement de Psychiatrie, CHRU de Strasbourg, Strasbourg, France; [3]The Wellcome Trust Centre for Neuroimaging, Institute of Neurology, University College London, London, UK

*To whom correspondence should be addressed; tel: +41-31-930-9334, fax: +41-31-930-9961, e-mail: tschacher@spk.unibe.ch

In recent decades, embodiment has become an influential concept in psychology and cognitive neuroscience. Embodiment denotes the study of the reciprocal (causal) relationships between mind and body, with the mind not only affecting the body but also vice versa. Embodied cognition comes to the fore in sensorimotor coupling, predictive coding, and nonverbal behavior. Additionally, the embodiment of the mind constitutes the basis of social interaction and communication, as evident in research on nonverbal synchrony and mimicry. These theoretical and empirical developments portend a range of implications for schizophrenia research and treatment. Sensorimotor dysfunctions are closely associated with affective and psychotic psychopathology, leading to altered timing in the processing of stimuli and to disordered appraisals of the environment. Problems of social cognition may be newly viewed as disordered embodied communication. The embodiment perspective suggests novel treatment strategies through psychotherapy and body-oriented interventions, and may ultimately provide biomarkers for diagnosis.

Key words: predictive coding/nonverbal synchrony/psychotherapy/mind–body relationship/sensorimotor processes/Bayesian statistics

Embodiment: Concept and Research

Embodiment addresses the relationship between mind and body. Is this relationship a circular one, is the mind (or the body) merely a reflection of the respective other, or are mind and body identical? These are, of course, foundational questions of philosophy that have been debated for centuries, and which have remained relevant to contemporary philosophy and the science of consciousness.[1] In the early 20th century, a number of philosophers, mainly originating from phenomenology, emphasized the significance of the living body for thinking.[2] In the present article, however, we will introduce embodiment not as a longstanding philosophical issue but as a current focus in sciences concerning the mind. Embodiment is playing an increasingly significant role as a construct of empirical psychology and cognitive science, which entails numerous implications for psychopathology. After a general introduction of the embodiment concept, we discuss its specific implications for schizophrenia—these range from cognitive functions to emotion, social interaction, and nonverbal communication. Finally, we will discuss the relevance of these perspectives for the treatment of people with schizophrenia.

The psychological construct "embodiment" implies reciprocal relationships between bodily-motor and cognitive-emotional processes.[3,4] This reciprocity or circular causality[5] is called the bidirectionality of embodiment. Each cognitive act, emotion, and affect has a sensorimotor component.[6] In a review[7] of embodiment in social-psychological research, this position was characterized by stating that all comprehension involves bodily simulation. This emphasizes quite generally the significance of the body for information processing; even abstract mathematical concepts contain sensorimotor ingredients. In overview, bodily variables such as facial expression, gestures, body movement, and postures influence a wide range of mental processes and their correlates—affects and emotions, motivation, attitudes, brain activity, reflexes, and neuroendocrine events.[8]

The embodiment approach in psychology, cognitive science, and social sciences carries with it a profound change in how cognition is conceptualized.[9] Embodiment explicitly acknowledges that the mind is embedded in a body. This departs fundamentally from traditional psychology: After its "cognitive turn," psychology had started to define cognition as a formal process of symbol manipulation in a physical symbol system.[10] Often referred to as the "computer metaphor of the mind," the physical symbol systems hypothesis also served as the foundation of artificial intelligence and computer science. The predominance of this metaphor, however, has waned (even in computer science),[11] which has turned to embodied agents (ie, robots) in its goal to study intelligence.[12] Modeling intelligence with an agent-based approach, instead of just formal symbol manipulation, has the advantage that action-perception cycles, ie, sensorimotor processes, can be used to improve an agent's adaptive functioning: using robots, artificial intelligence becomes grounded in the real world.[13,14] This has become particularly prescient in the context of informatics and foraging for information.[15] It is no longer considered sufficient to simply infer the causes of (sensory) data; sentient agents have to confront the epistemic problem of where to gather that information. The tools (ie, the body) we have at our disposal for this epistemic querying of our world become an integral part of active or embodied inference. This means the first thing an agent—robot or animal—has to mindfully learn, is what its body can do.[16]

In what follows, we review and defend the fundaments of embodiment. In the first (theoretical) half of the article, we address 2 core claims of the approach: We first propose that the inclusion of the body in cognition is consistent with contemporary systems neurobiology; namely, the concept of predictive coding. Second, we review research on the social corollaries of embodiment to show that motor behavior tacitly influences mental processes and, in the shape of interactional synchrony, forms the basis of social interaction. The second (implications) half of our treatment, claims that both predictive coding and social embodiment are specifically relevant to an improved understanding of the cognitive—as well as social—deficits characterizing schizophrenia. Finally, we consider prospective applications in the body-oriented treatment of schizophrenia.

Neurobiological Correlates of Embodiment

Embodied cognition has also been studied in a neurobiological context: Research on mirror neurons has shown that neuronal networks in the brain often have multiple functions, eg, the same neurons may be active when an action is performed by an animal, but also when an analogous action of another animal is perceived. Such observations may be regarded as a neuronal basis of sociality and empathy.[17]

On a more general level, neuronal dynamics can be viewed as cascades of feed-forward and feedback loops—of the sort proposed for motor control. Along these lines, some recent views on brain functioning generalize the dynamical principles of the mirror neuron system and of motor control to whole-brain functioning and thus represent an elementary form of embodiment.[18] The feedback loops of motor control entailed the following: A voluntary action is first planned by means of an inverse model (mapping from consequences to causes), which specifies the motor plan as a function of the action goal and of the environmental constraints under which the action is to be performed.[19] Once determined, a copy of the motor command, its efference copy, is used in a second internal model, the forward model (mapping from causes to consequences), to generate predictions regarding the sensory feedback (consequences) that would result from the action (causes) if it were to be performed. These predictions are compared to the real sensory feedback in order to nuance the action, if necessary, even before it has been completely executed. Hence, there is a continuous exchange of information between what is predicted, expected, and the sensory information that is actually experienced.

The generalization of these sensorimotor principles rests on the observation that this form of recursive optimization can be applied to a wide range of cognitive functions by the concept of predictive coding.[20,21] This ("active inference" or "enactive") approach applies Bayesian statistical theory to brain functioning, ie, it pursues the idea that a cognitive function requires the integration and exchange between incoming sensory information and assumptions or beliefs about the causes of sensory samples ("likelihood" and "priors," respectively in Bayesian terms). Visual illusions have confirmed that our perception does not faithfully reflect the outer world; rather, our perception is an optimal mixture of prior beliefs and sensory evidence based upon forward ("generative") models. This optimal mixture (known as the posterior belief) is approximated by flexible models of how our sensations are generated.[22] These models are tested by actively sampling the world to solicit information or data; enabling our internal models (our "virtual reality") to be improved—such that they acquire a better fit with the experienced world (that includes our physical bodies). Our subjective perception therefore involves an interpretation of the sensory signals, and both experimental-psychological[23,24] and electrophysiological[25,26] evidence suggest this relies on the integration of bottom-up and top-down signals. Thus, predictive coding theory goes beyond conventional models—that integrate bottom-up and top-down signals—to provide a neurobiologically plausible process theory for how the brain implements a dynamic updating of (Bayes) optimal beliefs about the world (and body).

In this view—optimization as a process of Bayesian belief updating—top-down signals are thought to convey predictions of incoming signals, based on the expected cause of those signals (ie, the Bayesian posterior belief or expectation, which is encoded by the activity of neuronal populations in cortical hierarchies). This general principle of an exchange between feed-forward (or ascending) sensory signals and feed-back (or descending) prior predictions can thus be easily applied to all cognitive functions including, yet not restricted to, motor control. In predictive coding, the ascending sensory signals are filtered so that only unexplained sensory information is fed forward. This nonredundant or "newsworthy" sensory information is called prediction error; leading to a reciprocal or recurrent exchange not only between the brain and body but between hierarchical levels of the brain. The overarching goal of this circular exchange of signals is to minimize prediction error.

This can be seen most intuitively in the principles of physiological homoeostasis, when we try to minimize the prediction errors between physiological sensations (eg, baroreceptor activity) and the levels (of, eg, blood pressure) set by prior expectations in the brainstem and beyond. In the theoretical literature, this perspective on active inference is known as interoceptive inference.[27–30] In motor control, prior expectations can be very context sensitive, changing quickly to prescribe a succession of equilibrium points for motor control.[31,32] A glossary of the terms commonly used in these theoretical formulations is provided in table 1.

Embodiment in Psychological Attitude Formation

Predictive coding and the ensuing active inference, as detailed above, views cognition as coupled to overt action, and in this sense represent the principle of embodiment in the neurobiological domain. This coupling is consistent with behavioral evidence of the body affecting the mind, and is thus complementary to the bidirectionality of mind and body as addressed in the broader discussion on embodiment. After more than 2 decades of empirical research on embodied cognition and embodied emotion in psychology, experimental evidence speaks to the many

Table 1. Glossary: Embodiment Terms and Their Definitions

Term	Definition	Citation
Active inference	Inferring the state of the environment, ie, perception, is not a passive response to sensory stimuli but an active process. Animals perceive by making predictions based on internal models (ie, "hypotheses" or "expectations") and resolving the resulting prediction error. This resolution can be through changing predictions or changing the sensations that are sampled. Inference is thus embodied: an active process of inferring the causes of sensations, which are selected by action.	Hobson and Friston[22]
Bayesian belief updating	The working mechanism of ↑ active inference: while executing a motor plan, prior beliefs and incoming sensory data—solicited by executing the plan—are continuously combined. In case of discrepancies, the actions (or predictions) may be adapted in order to minimize discrepancies (eg, prediction error).	Pezzulo et al[30]
Bayesian statistics	An approach to inference that enables one to evaluate the probability of a hypothesis H, given some evidence D. The *posterior probability* that H is true, given data D, depends on the *prior probability*, ie, the probability of H before we see D, and on the *likelihood*, ie, the probability of observing D given that H is true. In ↑ Bayesian belief updating, posteriors can be used as priors—for new data—to accumulate evidence for one's hypotheses.	
Embodiment	A concept emphasizing the reciprocal (bidirectional) relationship between mind (cognition, emotion) and body (motor behavior, nonverbal behavior, physiological processes).	Tschacher and Bergomi[33]
Enactivism	Enactivism claims that cognition and perception result from an active engagement with environmental constraints ("affordances"), rather than from the representation of the environment—a position closely related to ↑ active inference. The enactive approach views mind, body, and environment as highly interdependent elements of an (ecological) system.	Thompson and Varela[9]
Interoceptive inference	The notion of ↑ active inference can be generalized to interoception, ie, to perception and regulation of inner (physiological and visceral) processes. Interoceptive inference describes the (homeostatic) regulation of inner (autonomic) processes in the context of emotion and self-awareness.	Seth[27] and Gu and FitzGerald[28]
Mirror neuron system	Neuronal networks in the brain often have multiple functions: the same neurons may be active when executing an action and when perceiving the same action of another. Thus, action and action observation recruit the same neuronal (active inference) processes. This may be a neuronal correlate of empathy and mentalizing.	Rizzolatti and Craighero[17]
Nonverbal synchrony	In the interaction of A and B, nonverbal behavior of A tends to resonate with the nonverbal behavior of B, commonly without the intention to imitate or mimic. Synchrony (of motor behavior, physiological arousal, prosody) signals sensorimotor coupling—and is a bodily expression of prosocial emotions.	Chartrand and Bargh[34]
Optimal motor control	A formulation of motor control that rests on forward (and inverse) models of sensorimotor coupling. This usually involves generating an efference copy that is used to predict the sensory consequences of action. Discrepancies between the predicted and proprioceptive input are then used to adapt and fine-tune execution.	Wolpert et al.[19]
Predictive coding	Predictive coding is a ↑ Bayesian belief updating scheme for estimating the causes of (sensory) data by minimizing prediction error. It is a popular metaphor for (neuronal) message passing in the brain. This recurrent message passing takes place at different hierarchical levels of the cortex; where top-down processes generate predictions, and bottom-up signals report prediction errors.	Friston[20]

ways of body-mind exchanges. Bidirectionality means that mental processes influence the body, and body configurations find their expression in the mind. Whereas the first direction is consistent with traditional expectations in psychology (cognition and emotion entail action), the latter direction still seems rather unconventional. Nevertheless, a variety of studies have shown that manipulations of the body have an impact on mental states.

A well-known series of experiments on the "palm paradigm" was conducted by Cacioppo et al.[35] The paradigm was implemented in participants who were covertly instructed to realize 1 of 2 different postures: half of the participants were seated at a table and instructed to place both their palms on the top of the table and press lightly downwards so as to feel the muscular tension in their arms (arm flexion condition); the other half of the sample was instructed to place the palms under the table surface and exert pressure upwards (arm extension condition). During this "isometric muscle exercise," participants were asked to rate the pleasantness of neutral stimulus cards. The arm flexion group rated the stimuli as significantly more positive. This and numerous replications were interpreted as showing that the flexion condition tacitly realizes an embodiment of approach, whereas arm extension is associated with avoidance. Both embodiments were found to directly influence psychological attitudes towards stimuli and moderate subsequent approach or avoidance behaviors.

The embodied nature of perception and psychological evaluation is not restricted to motor behavior. For example, our perception of emotion depends, significantly, on when stimuli are presented during our cardiac cycle.[36] Such results also speak for a direct influence of embodiment: Experimentally induced facial expression, posture, autonomic status, etc. affect emotional responses directly, without mediating cognitive processes.

Embodiment in Social Interaction: Synchrony

Beyond such influences of body variables on mental process, social psychology was among the first fields to support the relevance of embodiment in interaction. As shown above, emotional processes can be caused by specific muscle activations such as arm flexion—body variables affect attitudes and appraisals.[37] Thus, embodiment must have implications for social interaction and communication where attitudes and emotional appraisals are essential elements. Again, social embodiment was previously discussed by phenomenology: Merleau-Ponty's *intercorporéité* means that my interaction partner is initially experienced via his/her body expression, which has an impact on me prior to my cognitive reflections. One basis of communication is thus intercorporeal resonance. In current psychological studies, this phenomenon has been operationalized and empirically observed as nonverbal synchrony.[38]

Synchrony is generally defined as the synchronization of components of a system, a core phenomenon of dynamical systems theory and complexity theory,[5] which provide appropriate theoretical backgrounds for both embodied cognition and communication.[33] In complex systems, one can distinguish between a micro- and macro-level, the former (bottom-) level containing the complexity of the system and the latter (top-) level the emerging patterns. Between both levels, bidirectional exchanges occur, which is analogous to the bidirectionality found in embodiment in general, and to the bottom-up and top-down signals of predictive coding.

The operationalization of synchrony as movement synchrony opened up a wide field of phenomena. In social interaction, synchrony arises spontaneously, often escaping the participants' attention. Examples are the alignments of body postures of people in close conversations.[39] The fact that interacting individuals are unaware of their synchrony points to a social phenomenon that is again not cognitively mediated and not an intentional element of action plans. Social synchrony arises independently of conscious information processing.

Social synchronization processes have been examined empirically (in healthy participants over a range of ages). Synchrony is already apparent in newborn infants who mimic caregivers' facial behavior.[40] Interactional synchrony of mother and child was associated with healthier attachment styles.[41] The Chameleon effect,[34] a concept of social-psychological research, denotes mimicry of nonverbal behavior in communication irrespective of age. As soon as one interaction partner observes the behavior of the other, the probability of the respective behavior in him/herself is involuntarily increased, which is also termed social contagion. Walkers in a group, for instance, tend to synchronize their gait. Emotional states appear to be contagious, ie, the joint probability of an expressed emotion is increased beyond the individual probabilities. This is true for expressions of emotions such as joy, sadness, or disgust. Contagion phenomena especially demonstrate one arm of bidirectionality, "mind as expression of the body," which characterizes embodiment.

Finally, in the theoretical context of active inference, generalized synchrony has been used as a fundamental mechanism for solving the hermeneutic problem of perspective-taking or "theory-of-mind": to infer another's state of mind or intentions, one can use the articulation (or speech) that I would generate if I had a particular intention. Thus, I can infer that you have the same intention given your articulation (or speech). The key trick behind this (Bayesian) solution to the theory-of-mind problem is to assume (a priori) that you have the same generative model as me. This means that—in any social interaction—we are both "singing from the same hymn sheet" and therefore share the same dynamical narrative. Simulations of active inference show that this form of (generalized) synchrony is entirely sufficient to communication, and is using the basic principles of predictive coding.[42] Indeed, synchronization underpins the ability of one (naive) agent to learn the embodied vocabulary of another.[43]

Implications for Schizophrenia

Embodied Cognition

The predictive coding or active inference formulation, using a Bayesian framework, is particularly pertinent for understanding conditions such as schizophrenia. This follows because most of the symptoms and signs of schizophrenia can be cast as false inference; in other words, false percepts and beliefs about the causes of sensations. The crucial insight afforded by embodiment is that much of perceptual inference rests on selecting the right sort of sensory evidence. This is the general problem of epistemic behavior; namely, choosing the right way to deploy our senses to get an optimal "grip" on the world.[44] Get this wrong and the brain-bound cascade of hierarchical predictive processing can easily lead to hallucinations and delusions—as we will see below.

Many research efforts have recently addressed predictive coding in schizophrenia. Several studies had already proposed that in motor control, the comparison between predicted and actual sensory feedback is impaired, possibly based on a disordered efference copy, ie, the copy of the motor program.[45,46] More generally, it has been hypothesized that the balance between sensory information and top-down beliefs is disordered in patients. According to several authors,[47,48] a failure in the neuromodulation of bottom-up signals[49] would lead to an increased weight of top-down signals, due to a compensatory mechanism. This would then increase the importance of priors, ie, beliefs, at the cost of sensory signals, representing a possible mechanism for the emergence of hallucinations and delusions. Predictions are based on available information, and the detection of prediction errors—the mismatch between predicted and actual sensory information—can be used to update and to reinterpret information. This updating depends upon the precision or salience afforded to ascending prediction errors, relative to descending predictions. In consequence, dysfunctional or aberrant salience or precision in predictive coding would confound updating, thereby enabling delusional interpretations.[50–52] (Although which mechanisms are impaired, whether bottom-up or top-down, remains to be determined.)

Crucially, predictive coding associated with motor actions and language allows us to disambiguate between self-generated and externally generated signals. This attribution about agency can be easily confounded by aberrant inference, leading to different types of self-disorders, whereby patients do not recognize their inner discourse, their own actions or body as their own.[53] The former may underlie hallucinations[54,55] whereas the latter may be involved in delusions of control[44,45] or, in case of body ownership disorders, in depersonalization.[56–59] This false inference model of psychopathology still requires full confirmation, but a series of results suggest impairments that are consistent with this formulation. We offer some examples here.

Psychotic cognition may be disordered already at an elementary level, preventing patients from predicting and following sensory signals from moment to moment.[60,61] The existence of loops of signal processing implies a certain refresh rate for information updating, which allows 2 events to be distinguished in time.[62,63] According to recent evidence, the automatic updating of sensory information is impaired in schizophrenia.[64,65] Sensory processing would be fragmented, which might affect the patients' ability to feel as being immersed in the world, and to experience themselves as one single and continuing entity.[66,67] This would thus lead to bodily, or "minimal self" disorders, that have been described in prodromal patients as well as in chronic patients.[68,69]

A number of results are issued from research on action, whether ocular[70] or manual. A key part of prediction in active vision is the ability to deploy saccadic eye movements to sample salient information. Interestingly, abnormal pursuit and saccadic eye movements are one of the most consistent (soft-neurological) signs in schizophrenia. Furthermore, exactly the same abnormal (precision) weighting of sensory evidence described above—in relation to top-down prior predictions—can explain some of the cardinal deficits of pursuit movements in schizophrenia.[71] The emerging picture from the perspective of active inference is that psychotic disorders can be traced back to a failure of sensory attenuation; namely a failure to down-weight sensory evidence during self-generated movement.[72]

This is manifest in several contexts. An interesting example is the force-matching illusion—a force is applied to the left index finger either by one's own right index finger or by a hidden apparatus. If the force is self-generated, the sensation in the left finger is usually attenuated, and the activation in the somatosensory cortex down-regulated. This however is not true in people with schizophrenia, and the lack of sensory attenuation was associated with their severity of hallucinatory experiences.[73] Again, this may be explained by dysfunctional predictive coding—to "rescue" the false inference associated with failures of sensory attenuation, it might be necessary to call on prior beliefs with undue precision or confidence.[74] This sort of argument casts much of psychotic psychopathology in terms of false inference (eg, delusions as false beliefs and hallucinations as false percepts). Crucially, a failure of sensory attenuation rests upon an active sampling of the world—and the body. These examples speak to a fundamental role for the body, not just in embodied cognition but the embodied perception implicit in visual palpation of the world.

Psychotherapy

Psychological interventions, especially psychotherapy, are important tools to achieve clinical and functional recovery in schizophrenic psychoses.[75] Even if academic psychotherapy research still tends to neglect aspects of nonverbal behavior and embodiment,[76] practitioners know that relevant information about patients and the therapeutic alliance is conveyed in this way. Psychotherapy is an example of embodied social interaction, characterized by synchronization: During verbal exchange, patient and therapist move in response to each other, coordinating posture changes, seating positions, gestures, facial expressions, and movements. Controlled studies have shown that synchrony, defined via the cross-correlations of therapist's and patient's body movements, occurs significantly in psychotherapeutic interactions.[77] Nonverbal synchrony has considerable associations with therapy process and outcome. For instance, nonverbal synchrony is a behavioral marker of a positive therapeutic alliance and is increased in patients with higher levels of self-efficacy—synchrony is linked with these and further "common factors" of psychotherapy. In line with such findings, nonverbal synchrony predicted positive psychotherapy outcome and symptom reduction. Synchrony was attenuated when patients had higher levels of psychopathology, interpersonal problems, and less secure attachment styles (which latter finding resonates with the synchrony findings of parent–infant dyads mentioned earlier[41]).

A conclusion of accumulating findings is that psychotherapy is less of Freud's "talking cure" (*Redekur*) than is tacitly assumed by many psychotherapy researchers, and may be more about embodied synchronization with a "talking core." In addition to insight and other cognitive change factors, dynamically coordinated bodily movements significantly contribute to therapy effectiveness.

Embodied Emotion

Emotional states are embodied in physical movement. A common observation is that sadness is reflected by attenuated motor activity; the inhibition of psychomotor activity is a key feature of depression.[78] Correspondingly, a behavioral technique for treating depressive symptoms, common in schizophrenia, is through increased activity levels, such as sporting activities. The observation that physical activity is negatively associated with depressive affect is supported by many studies that used actigraphy (eg, 24 h recordings of movement by sensors worn on the wrist) to monitor patients and healthy individuals. Specific features of motor activity can distinguish symptoms in depression and schizophrenia. Subtle, but significant, differences were found between these patient groups.[79] For instance, schizophrenia patients showed higher entropy in actigraphic recordings, ie, higher disorder of movement than both depression patients and healthy controls.

Gait patterns, ie, the style of walking, have been studied in the context of embodied depressive emotions.[80] The gait of participants walking on a treadmill was continuously monitored by motion capturing. Using biofeedback, in half of a healthy sample a happy walking style was induced, and depressed walking in the other (small arm-swings, less vertical movements, larger lateral sway, slumped forward-leaning posture). The study showed that the depressed walkers developed an affective memory bias: the well-studied symptom that stimuli with negative valence are encoded and recalled better in depressed affective states. Thus, embodiment markers such as qualitative styles of gait may have an impact on the vulnerability to depression, with implications for affective disorders as well as affective symptoms of schizophrenia.

Using actigraphic measurements of schizophrenia patients' movement, reduced activity levels have been repeatedly reported, which is consistent with the attenuated motor activity due to depression and negative symptoms of psychosis. Apart from the amount of movement, however, further properties of movement were linked with symptoms.[81] The temporal organization (assessed by autocorrelations) of one-hour actigraphic recordings of body movement was associated to the positive, disorganization, and excitement factors of the Positive and Negative Syndrome Scale (PANSS).[82] Reduced body-movement organization was a marker of enhanced psychotic symptomatology in schizophrenia patients. Different parameters of body movement thus appear to be differentially linked with affective and psychotic symptom factors in schizophrenia, a topic that calls for further research.

Embodied Communication

In the European tradition of psychopathology, problems of the self (*Ich-Störungen*) have been viewed as belonging to the "clinical core of schizophrenia."[83] Yet, the core of schizophrenia is increasingly implicating bodily and communicative processes.[84] Several studies have investigated the nonverbal behavior of schizophrenia patients, such as reduced facial expression.[85] Deficits in social skills have been analyzed using observer-based rating scales,[86] and more recently, also objective measures of movement.

Patients showed less nonverbal communication activity, which was compensated by their healthy partners' nonverbal effort.[87] The negative factor, measured using the PANSS, was correlated especially with reduced head, and to a lesser degree body, movement of patients[88] during conversations. Disorganization symptoms were related to lower movement speed of the body.

Research on nonverbal synchrony of patients and healthy interaction partners extend such findings. The nonverbal coordination of their head movements is generally reduced during dyadic conversations.[89] Differential profiles of such attenuated synchrony were observed depending on the symptoms of the patients: In the presence of cognitive and positive symptoms, interaction partners responded less to patients' movement activity, whereas in negative and affective symptoms, it was the patients who were less responsive.

Clinical Applications in Schizophrenia

The close bidirectional liaison of mind and body opens up opportunities for translation into treatment. The above examples have illustrated the remarkable explanatory power of predictive coding, nonverbal synchrony, and psychomotor variables. Many possible clinical applications remain to be explored. Yet, some therapeutic implications of the embodiment approach are already evident.

The principles of embodiment have instigated interventions both for affective disorders and schizophrenia. In major depression, ample evidence exists for the benefits of behavioral activation[90] alone. Such findings are relevant for schizophrenia where affective symptoms are common. The efficacy of body-oriented psychological therapy specifically for schizophrenia was supported by randomized-controlled studies.[91,92] A manual was developed aiming to increase body awareness and to moderate dysfunctional self-perception, thereby promoting emotional expression and interpersonal responsiveness. The treatments included individual, dyadic and group exercises. Benefits were found in the alleviation especially of negative symptoms—suggesting that different change mechanisms may be at work than in neuroleptic treatment or cognitive psychotherapy.

Several approaches to modify social cognition in schizophrenia have been introduced by integrated treatment programs and interventions focusing on social cognition.[93] Body-oriented psychotherapy extends the focus from social *cognition* to real social behavior. Therapy approaches have integrated mimicry to help patients recognize emotions.[94] Such novel treatment approaches can be based on findings using functional MRI that showed less fine-tuning of the mirror-neuron system when patients were observing biological motion.[95] Disorganized nonverbal behavior plays a significant role in social impairments, as was also suggested by the findings on nonverbal synchrony.[89] Embodiment concepts have been applied when using avatars to improve gaze behavior.[96] Efficacy research on embodied therapy approaches, however, is at an early stage still, and further randomized-controlled trials are needed.

A future application of embodiment research rests in using body parameters in diagnostics, which is even less developed than the search for direct therapeutic implementations. Psychiatric diagnostics is still predominantly phenomenological. Correspondingly, there are topics of medical folklore such as the "praecox feeling,"[97] which is supposed to signal the presence of schizophrenia in an as yet undiagnosed patient. The praecox feeling relates to similar notions (diagnosis per "intuition" or "penetration"), which may in fact be grounded in aspects of embodied communication, such as patients' reduced or impaired use of gestures.[98] We foresee that embodiment research may define behavioral markers for psychopathological conditions that can be obtained conveniently in a clinical setting—embodiment markers may ultimately fulfill the longstanding promise of neurobiological definitions of psychiatric disorders.

Funding

K.F. is funded by a Wellcome Trust Principal Research Fellowship (Ref: 088130/Z/09/Z).

Acknowledgments

The authors have declared that there are no conflicts of interest in relation to the subject of this study.

References

1. Chalmers DJ, ed. *Philosophy of Mind: Classical and Contemporary Readings*. Oxford: Oxford University Press; 2002.
2. Merleau-Ponty M. *Phénoménologie de la perception*. Paris: Gallimard; 1945.
3. Niedenthal PM. Embodying emotion. *Science*. 2007;316:1002–1005.
4. Liepelt R, Dolk T, Prinz W. Bidirectional semantic interference between action and speech. *Psychol Res*. 2012;76:446–455.
5. Haken H. *Synergetics. An introduction*. Berlin: Springer; 1977.
6. Barsalou LW. Simulation, situated conceptualization, and prediction. *Philos Trans R Soc Lond B Biol Sci*. 2009;364:1281–1289.
7. Meier B, Schnall S, Schwarz N, Bargh J. Embodiment in social psychology. *Top Cogn Sci*. 2012;4:1–12.
8. Price T, Peterson C, Harmon-Jones E. The emotive neuroscience of embodiment. *Motiv Emot*. 2012;36:27–37.
9. Thompson E, Varela FJ. Radical embodiment: neural dynamics and consciousness. *Trends Cogn Sci*. 2001;5:418–425.
10. Newell A. Physical symbol systems. *Cogn Sci*. 1980;4:135–183.
11. Tenenbaum JB, Kemp C, Griffiths TL, Goodman ND. How to grow a mind: statistics, structure, and abstraction. *Science*. 2011;331:1279–1285.
12. Pfeifer R, Scheier C. *Understanding Intelligence*. Cambridge: MIT Press; 1999.
13. Ferro M, Ognibene D, Pezzulo G, Pirrelli V. Reading as active sensing: a computational model of gaze planning in word recognition. *Front Neurorobot*. 2010;4:6.
14. Tani J, Nolfi S. Learning to perceive the world as articulated: an approach for hierarchical learning in sensory-motor systems. *Neural Netw*. 1999;12:1131–1141.
15. Friston K, Rigoli F, Ognibene D, Mathys C, Fitzgerald T, Pezzulo G. Active inference and epistemic value. *Cogn Neurosci*. 2015;6:187–214.
16. Saegusa R, Metta G, Sandini G, Sakka S. Active motor babbling for sensorimotor learning. *IEEE Proc Int Conf Robot Biomimetics*. 2008;794–799.

17. Rizzolatti G, Craighero L. The mirror-neuron system. *Annu Rev Neurosci*. 2004;27:169–192.
18. Wolpert DM, Doya K, Kawato M. A unifying computational framework for motor control and social interaction. *Philos Trans R Soc Lond B Biol Sci*. 2003;358:593–602.
19. Wolpert DM, Ghahramani Z, Jordan MI. An internal model for sensorimotor integration. *Science*. 1995;269:1880–1882.
20. Friston K. A theory of cortical responses. *Philos Trans R Soc Lond B Biol Sci*. 2005;360:815–836.
21. Friston K. Hierarchical models in the brain. *PLOS Comput Biol*. 2008;4:e1000209.
22. Hobson JA, Friston KJ. Consciousness, dreams, and inference. The Cartesian theatre revisited. *J Conscious Stud*. 2014;21:6–32.
23. Kimchi R. Uniform connectedness and grouping in the perceptual organization of hierarchical patterns. *J Exp Psychol Hum Percept Perform*. 1998;24:1105–1118.
24. Beck DM, Palmer SE. Top-down influences on perceptual grouping. *J Exp Psychol Hum Percept Perform*. 2002;28:1071–1084.
25. Bullier J, Hupé JM, James AC, Girard P. The role of feedback connections in shaping the responses of visual cortical neurons. *Prog Brain Res*. 2001;134:193–204.
26. Lamme VA, Roelfsema PR. The distinct modes of vision offered by feedforward and recurrent processing. *Trends Neurosci*. 2000;23:571–579.
27. Seth AK. Interoceptive inference, emotion, and the embodied self. *Trends Cogn Sci*. 2013;17:565–573.
28. Gu X, FitzGerald TH. Interoceptive inference: homeostasis and decision-making. *Trends Cogn Sci*. 2014;18:269–270.
29. Barrett LF, Simmons WK. Interoceptive predictions in the brain. *Nat Rev Neurosci*. 2015;16:419–429.
30. Pezzulo G, Rigoli F, Friston K. Active inference, homeostatic regulation and adaptive behavioural control. *Prog Neurobiol*. 2015;134:17–35.
31. Adams RA, Shipp S, Friston KJ. Predictions not commands: active inference in the motor system. *Brain Struct Funct*. 2013;218:611–643.
32. Mirza MB, Adams RA, Mathys CD, Friston KJ. Scene construction, visual foraging, and active inference. *Front Comput Neurosci*. 2016;10:56.
33. Tschacher W, Bergomi C, eds. *The Implications of Embodiment: Cognition and Communication*. Exeter: Imprint Academic; 2011.
34. Chartrand TL, Bargh JA. The chameleon effect: the perception-behavior link and social interaction. *J Pers Soc Psychol*. 1999;76:893–910.
35. Cacioppo JT, Priester JR, Berntson GG. Rudimentary determinants of attitudes. II: arm flexion and extension have differential effects on attitudes. *J Pers Soc Psychol*. 1993;65:5–17.
36. Garfinkel SN, Critchley HD. Threat and the body: how the heart supports fear processing. *Trends Cogn Sci*. 2016;20:34–46.
37. Prigent E, Amorim MA, Leconte P, Pradon D. Perceptual weighting of pain behaviours of others, not information integration, varies with expertise. *Eur J Pain*. 2014;18:110–119.
38. Tschacher W, Rees GM, Ramseyer F. Nonverbal synchrony and affect in dyadic interactions. *Front Psychol*. 2014;5:1323.
39. Grammer K, Kruck KB, Magnusson MS. The courtship dance: patterns of nonverbal synchronization in opposite-sex encounters. *J Nonverbal Behav*. 1998;22:3–29.
40. Meltzoff AN, Moore MK. Newborn infants imitate adult facial gestures. *Child Dev*. 1983;54:702–709.
41. Isabella RA, Belsky J. Interactional synchrony and the origins of infant–mother attachment: a replication study. *Child Dev*. 1991;62:373–384.
42. Friston KJ, Frith CD. Active inference, communication and hermeneutics. *Cortex*. 2015;68:129–143.
43. Friston K, Frith C. A duet for one. *Conscious Cogn*. 2015;36:390–405.
44. Bruineberg J, Rietveld E. Self-organization, free energy minimization, and optimal grip on a field of affordances. *Front Hum Neurosci*. 2014;8:599.
45. Franck N, Farrer C, Georgieff N, et al. Defective recognition of one's own actions in patients with schizophrenia. *Am J Psychiatry*. 2001;158:454–459.
46. Frith C. The neural basis of hallucinations and delusions. *C R Biol*. 2005;328:169–175.
47. Picard F, Friston K. Predictions, perception, and a sense of self. *Neurology*. 2014;83:1112–1118.
48. Notredame CE, Pins D, Deneve S, Jardri R. What visual illusions teach us about schizophrenia. *Front Integr Neurosci*. 2014;8:63.
49. Shergill SS, Samson G, Bays PM, Frith CD, Wolpert DM. Evidence for sensory prediction deficits in schizophrenia. *Am J Psychiatry*. 2005;162:2384–2386.
50. Adams RA, Stephan KE, Brown HR, Frith CD, Friston KJ. The computational anatomy of psychosis. *Front Psychiatry*. 2013;4:47.
51. Jardri R, Denève S. Circular inferences in schizophrenia. *Brain*. 2013;136:3227–3241.
52. Fineberg SK, Corlett PR. The doxastic shear pin: delusions as errors of learning and memory. *Cogn Neuropsychiatry*. 2016;21:73–89.
53. Sterzer P, Mishara AL, Voss M, Heinz A. Thought insertion as a self-disturbance: an integration of predictive coding and phenomenological approaches. *Front Hum Neurosci*. 2016;10:502.
54. Horga G, Schatz KC, Abi-Dargham A, Peterson BS. Deficits in predictive coding underlie hallucinations in schizophrenia. *J Neurosci*. 2014;34:8072–8082.
55. Teufel C, Subramaniam N, Dobler V, et al. Shift toward prior knowledge confers a perceptual advantage in early psychosis and psychosis-prone healthy individuals. *Proc Natl Acad Sci U S A*. 2015;112:13401–13406.
56. Northoff G, Stanghellini G. How to link brain and experience? Spatiotemporal psychopathology of the lived body. *Front Hum Neurosci*. 2016;10:76.
57. Northoff G. Resting state activity and the "stream of consciousness" in schizophrenia–neurophenomenal hypotheses. *Schizophr Bull*. 2015;41:280–290.
58. Michael J, Park S. Anomalous bodily experiences and perceived social isolation in schizophrenia: an extension of the social deafferentation hypothesis. *Schizophr Res*. 2016;176:392–397.
59. Haug E, Øie MG, Andreassen OA, et al. The association between anomalous self-experiences, self-esteem and depressive symptoms in first episode schizophrenia. *Front Hum Neurosci*. 2016;10:557.
60. Lalanne L, van Assche M, Giersch A. When predictive mechanisms go wrong: disordered visual synchrony thresholds in schizophrenia. *Schizophr Bull*. 2012;38:506–513.
61. Lalanne L, Van Assche M, Wang W, Giersch A. Looking forward: an impaired ability in patients with schizophrenia? *Neuropsychologia*. 2012;50:2736–2744.
62. Elliott MA, Shi Z, Kelly SD. A moment to reflect upon perceptual synchrony. *J Cogn Neurosci*. 2006;18:1663–1665.

63. Giersch A, Lalanne L, van Assche M, Elliott MA. On disturbed time continuity in schizophrenia: an elementary impairment in visual perception? *Front Psychol*. 2013;4:281.
64. Turgeon M, Giersch A, Delevoye-Turrell Y, Wing AM. Impaired predictive timing with spared time interval production in individual with schizophrenia. *Psychiatry Res*. 2012;197:13–18.
65. Delevoye-Turrell Y, Wilquin H, Giersch A. A ticking clock for the production of sequential actions: where does the problem lie in schizophrenia? *Schizophr Res*. 2012;135:51–54.
66. Martin B, Wittmann M, Franck N, Cermolacce M, Berna F, Giersch A. Temporal structure of consciousness and minimal self in schizophrenia. *Front Psychol*. 2014;5:1175.
67. Mishara AL. Is minimal self preserved in schizophrenia? A subcomponents view. *Conscious Cogn*. 2007;16:715–721.
68. Nelson B, Parnas J, Sass LA. Disturbance of minimal self (ipseity) in schizophrenia: clarification and current status. *Schizophr Bull*. 2014;40:479–482.
69. Hur JW, Kwon JS, Lee TY, Park S. The crisis of minimal self-awareness in schizophrenia: a meta-analytic review. *Schizophr Res*. 2014;152:58–64.
70. Thakkar KN, Schall JD, Heckers S, Park S. Disrupted saccadic corollary discharge in schizophrenia. *J Neurosci*. 2015;35:9935–9945.
71. Adams RA, Perrinet LU, Friston K. Smooth pursuit and visual occlusion: active inference and oculomotor control in schizophrenia. *PLoS One*. 2012;7:e47502.
72. Lencer R, Sprenger A, Reilly JL, et al. Pursuit eye movements as an intermediate phenotype across psychotic disorders: evidence from the B-SNIP study. *Schizophr Res*. 2015;169:326–333.
73. Shergill SS, White TP, Joyce DW, Bays PM, Wolpert DM, Frith CD. Functional magnetic resonance imaging of impaired sensory prediction in schizophrenia. *JAMA Psychiatry*. 2014;71:28–35.
74. Brown H, Adams RA, Parees I, Edwards M, Friston K. Active inference, sensory attenuation and illusions. *Cogn Process*. 2013;14:411–427.
75. Wykes T, Steel C, Everitt B, Tarrier N. Cognitive behavior therapy for schizophrenia: effect sizes, clinical models, and methodological rigor. *Schizophr Bull*. 2008;34:523–537.
76. Lambert MJ, ed. *Bergin and Garfield's Handbook of Psychotherapy and Behavior Change*. 6th ed. New York: Wiley; 2013.
77. Ramseyer F, Tschacher W. Nonverbal synchrony in psychotherapy: coordinated body movement reflects relationship quality and outcome. *J Consult Clin Psychol*. 2011;79:284–295.
78. Schrijvers D, Hulstijn W, Sabbe BG. Psychomotor symptoms in depression: a diagnostic, pathophysiological and therapeutic tool. *J Affect Disord*. 2008;109:1–20.
79. Hauge ER, Berle JØ, Oedegaard KJ, Holsten F, Fasmer OB. Nonlinear analysis of motor activity shows differences between schizophrenia and depression: a study using Fourier analysis and sample entropy. *PLoS One*. 2011;6:e16291.
80. Michalak J, Rohde K, Troje NF. How we walk affects what we remember: gait modifications through biofeedback change negative affective memory bias. *J Behav Ther Exp Psychiatry*. 2015;46:121–125.
81. Walther S, Ramseyer F, Horn H, Strik W, Tschacher W. Less structured movement patterns predict severity of positive syndrome, excitement, and disorganization. *Schizophr Bull*. 2014;40:585–591.
82. Kay SR, Fiszbein A, Opler LA. The positive and negative syndrome scale (PANSS) for schizophrenia. *Schizophr Bull*. 1987;13:261–276.
83. Parnas J. A disappearing heritage: the clinical core of schizophrenia. *Schizophr Bull*. 2011;37:1121–1130.
84. Stanghellini S. Embodiment and schizophrenia. *World Psychiatry*. 2009;8:56–59.
85. Trémeau F, Malaspina D, Duval F, et al. Facial expressiveness in patients with schizophrenia compared to depressed patients and nonpatient comparison subjects. *Am J Psychiatry*. 2005;162:92–101.
86. Brüne M, Sonntag C, Abdel-Hamid M, Lehmkämper C, Juckel G, Troisi A. Nonverbal behavior during standardized interviews in patients with schizophrenia spectrum disorders. *J Nerv Ment Dis*. 2008;196:282–288.
87. Lavelle M, Healey PG, McCabe R. Is nonverbal communication disrupted in interactions involving patients with schizophrenia? *Schizophr Bull*. 2013;39:1150–1158.
88. Kupper Z, Ramseyer F, Hoffmann H, Kalbermatten S, Tschacher W. Video-based quantification of body movement during social interaction indicates the severity of negative symptoms in patients with schizophrenia. *Schizophr Res*. 2010;121:90–100.
89. Kupper Z, Ramseyer F, Hoffmann H, Tschacher W. Nonverbal synchrony in social interactions of patients with schizophrenia indicates socio-communicative deficits. *PLoS One*. 2015;10:e0145882.
90. Dimidjian S, Hollon SD, Dobson KS, et al. Randomized trial of behavioral activation, cognitive therapy, and antidepressant medication in the acute treatment of adults with major depression. *J Consult Clin Psychol*. 2006;74:658–670.
91. Röhricht F, Priebe S. Effect of body-oriented psychological therapy on negative symptoms in schizophrenia: a randomized controlled trial. *Psychol Med*. 2006;36:669–678.
92. Martin LA, Koch SC, Hirjak D, Fuchs T. Overcoming disembodiment: the effect of movement therapy on negative symptoms in schizophrenia—a multicenter randomized controlled trial. *Front Psychol*. 2016;7:483.
93. Kurtz MM, Richardson CL. Social cognitive training for schizophrenia: a meta-analytic investigation of controlled research. *Schizophr Bull*. 2012;38:1092–1104.
94. Pino MC, Pettinelli M, Clementi, Gianfelice C, Mazza M. Improvement in cognitive and affective theory of mind with observation and imitation treatment in subjects with schizophrenia. *Clin Neuropsychiatry*. 2015;12:64–72.
95. Thakkar KN, Peterman JS, Park S. Altered brain activation during action imitation and observation in schizophrenia: a translational approach to investigating social dysfunction in schizophrenia. *Am J Psychiatry*. 2014;171:539–548.
96. Timmermans B, Schilbach L. Investigating alterations of social interaction in psychiatric disorders with dual interactive eye tracking and virtual faces. *Front Hum Neurosci*. 2014;8:758.
97. Rümke HC. Das Kernsyndrom der Schizophrenie und das Praecox-Gefühl. *Zentralblatt gesamte Neurol Psychiatr*. 1941;102:168–169.
98. Walther S, Mittal VA. Why we should take a closer look at gestures. *Schizophr Bull*. 2016;42:259–261.