The bodily self and its disorders: neurological, psychological and social aspects

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The bodily self and its disorders: neurological, psychological and social aspects

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Purpose of review
The experience of ourselves as an embodied agent with a first-person perspective is referred to as 'bodily self'. We present a selective overview of relevant clinical and experimental studies.

Recent findings
Sharing multisensory body space with others can be observed in patients with structurally altered bodies (amputations, congenital absence of limbs), with altered functionality after hemiplegia, such as denial of limb ownership (somatoparaphrenia) and with alterations in bodily self-consciousness on the level of the entire body (e.g. in autoscopic phenomena). In healthy participants, the mechanisms underpinning body ownership and observer perspective are empirically investigated by multisensory stimulation paradigms to alter the bodily self. The resulting illusions have promoted the understanding of complex disturbances of the bodily self, such as out-of-body experiences. We discuss the role of interoception in differentiating between self and others and review current advances in the study of body integrity identity disorder, a condition shaped as much by neurological as by social-psychological factors.

Summary
We advocate a social neuroscience approach to the bodily self that takes into account the interactions between body, mind and society and might help close the divide between neurology and psychiatry.

Keywords
body integrity identity disorder, illusion paradigms, interoception, social neuroscience

INTRODUCTION

Human beings are self-conscious individuals whose thinking and behaviour is grounded in basic bodily processes. These processes transcend the sole domains of somatosensation and motor action; our body can be seen, its parts can be localized in space in pitch darkness, we know where we are heading to, and can follow our heart. Body space is a multisensory space, continuously made up by exteroceptive, proprioceptive and interoceptive impressions. The bodily self is made up of the multiple interactions between these impressions. Accordingly, the range of disorders affecting a person's bodily self is considerable; the body can be experienced as lost, not belonging, not under control, empty, ugly, detached or duplicated.

Human beings represent a social species. However private and intimate a person's body may appear, bodily selves leap out to embrace the space they share with others; 'body image is a social phenomenon' ([1], p. 217). Social neuroscience strives at understanding the interplay between neural, psychological, social and cultural processes. Although the brain–computer metaphor may serve to illustrate those disorders of the 'body-in-the-brain' [2] that have classically been treated in neurological textbooks, a social neuroscience of corporeal awareness needs to adapt its metaphors to the 'body-in-the-brain-in-society'. Brains thus rather resemble cell phones [3], whose broadband connectivity enables a person to swiftly navigate social space and to get in touch with conspecifics' embodied selves.

Against this background, our opinion review is presented in three parts. We first discuss recent advances on some classic disorders of the bodily self, emphasizing empirical studies that help

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KEY POINTS

- Disorders of the bodily self span all levels of body representation, from single limbs to the entire body in a social context.
- Integration of exteroceptive and interoceptive information underpins the bodily self and self-other distinction.
- Many disorders of the bodily self are shaped by both neurological and social factors; we discuss body integrity identity disorder (BIID) as a paradigmatic case.
- A social neuroscience approach is needed to fully understand the bodily self and its disturbances.

transcend the view of the bodily self as an exclusively private issue. We will then comment on what we think is probably the most significant trend in the research literature, that is the increasing attention given to interoceptive awareness. It may read paradoxical, but the sense of the interior condition of our body may open up a window to the understanding of others. Finally, we consider one unusual condition, body integrity identity disorder (BIID), which seems to ideally exemplify how neurological factors and higher-level social norms can both significantly contribute to the experience of body and self as a unity.

NEUROLOGY OF THE BODILY SELF: FROM SINGLE LIMBS TO WHOLE BODIES

Phantom phenomena illustrate that the bodily self does not necessarily match the physical body. They are observed after the loss of limbs, but also in hemiplegia, that is after deafferentation of a hemibody or, in autoscopic reduplication, of one's entire body [4,5].

The phantom limb

Phantom limb phenomena have always fascinated neurologists, philosophers and layman alike. Invisible, yet frequently pictured [6▪], they nicely illustrate that the borders of the bodily self do not need to correspond to the borders set by bone and flesh. Research on phantom sensations has focused on phantom pain ([7] for a review), whose underlying mechanisms are currently controversially discussed; the classical view of painful phantom sensations as the consequence of maladaptive reorganization [8] was challenged by data suggesting that pain is rather associated with preserved function and structure in the deprived cortical area, but reduced functional connectivity in primary somatosensory cortex [9▪]. Nonpainful phantom sensations do not seem to be related to the same reorganizational processes and appear to rely more on posterior parietal areas. A transcranial direct current stimulation study showed alleviation of painful phantom sensations after stimulation over sensorimotor areas and suppression of nonpainful phantom sensations with posterior parietal stimulation [10]. Although these observations are important, they do not address the merging of the bodily self with others, a process presumably mediated by the mirror system [11▪]. Extensive experimentation with a person born without arms (but no phantom sensations) revealed that the visual identification of manipulable artefacts allows action comprehension in the absence of motor representations [12,13▪]. Such observations are important because they constrain theories of phantom sensations in limb aplasia [14]. Not commenting on presence or absence of phantom sensations is therefore inexcusable in any report on persons with congenitally absent limbs, as elucidating the employed paradigms may be [15,16]. Complementary to the above findings, normally limbed individuals can 'merge' with the body representation of a visually observed armless person, and they do so as a function of their cognitive-emotional empathy [17▪]. Also after traumatic amputation, empathy seems to facilitate the referral of touch observed on others' bodies onto the phantom limb [18]. Finally, work in healthy participants documented the influence of empathy as well as social perception on the bodily self and shared body representations ([19–21] for reviews).

Somatoparaphrenia

Patients with anosognosia for their hemiplegia sometimes deny ownership of the paralyzed part of their body, claiming that it belongs to somebody else, often a close relative or a person of the care team. Once poignantly labelled 'personification anosognosia' [22], somatoparaphrenia represents the 'filling in' of a deafferented body part by the phantom presence of somebody else.

Recent work in the field has shown that anosognosia and somatoparaphrenia are dissociable [23], and the loss of ownership, but not the loss of insight into paralysis, is accompanied by a reduced autonomous response to incoming threat [24]. Having patients with somatoparaphrenia adopt a third-person perspective can drastically change bodily self-consciousness. For instance, viewing one's own hand in a mirror (as if one observed it from the perspective of another person) abolished somatoparaphrenia in one patient [25], while intermanual

coupling emerged in a bimanual circle-and-line drawing task [26▪] as long as patients incorporated another person's moving hand. Together, these clinical and experimental findings suggest that the borders of private space critically depend on whether one takes an egocentric perspective or a perspective centred on a location in the space shared with others.

Autoscopic phenomena

The issue of perspective is key when it comes to autoscopic phenomena, which can be conceived as phantoms of the entire body. Their taxonomy had originally been based on clinical phenomenology [27] and has now received support by quantitative lesion analysis [28▪▪]. An autoscopic hallucination is the visual experience of seeing oneself as in a mirror. The perspective is clearly embodied, the hallucination normally unimodal and, if confined to one visual field, almost always to the left. Accordingly, the major lesion site was found to involve right extrastriate cortex. In contrast, the neuroanatomical substrate of heautoscopy is quite different. Heautoscopy is the highly emotional encounter with a 'phantom double' [29] of oneself, who moves independently and makes a patient wonder whether the observer perspective is centred on the body or the phantom. Lesion overlap analysis highlighted the left posterior insula, whose damage would produce a disintegration between emotional and interoceptive signals, and the resulting strong psychological affinity with the double would make self-localization undetermined. Such projective duplication is in fact at the heart of literary descriptions of heautoscopy (thoroughly and thrillingly reviewed in [30▪]), as the relative autonomy of the double and the ambiguity of self-localization provide the seeds for the sometimes dramatic and often profoundly symbolic content of *doppelgänger* episodes. The work by Heydrich and Blanke [28▪▪] is important in its attempt to link phenomenology and functional anatomy. Some questions remain open, however. It seems, for instance, that the opposite hemispheric involvement in autoscopic hallucinations and heautoscopy reside unexplained as long as symptom-lesion mappings will not consider the phenomenology of individual heautoscopic episodes in more detail. We know from nonbodily visual hallucinations that their emotional valence can be strongly associated with the visual half-field in which the action unfolds [31]. It is conceivable that lesion laterality determines to a large part whether doubles take a predominantly consoling or a more antagonistic role.

Simulated out-of-body illusion in healthy persons

Among the autoscopic phenomena not subject to lesion analysis by the authors [28▪▪] is the out-of-body experience (OBE, but see [32]). This is the illusion of seeing one's own body from the outside. Ever since the first description of a method that induces an OBE-like apparent separation between body and self in healthy research participants (the 'full-body illusion'; see Table 1) [33,34▪,35–42,43▪▪, 44–48,49▪,50▪,51,52,53▪▪,54–60,61▪,62,63], modifications of the technique have mushroomed. Apart from the different variations in procedure, interesting physiological correlates of experimentally induced changes in the bodily self have been described. These range from a change in skin temperature (a measure long been known to reflect changes in bodily awareness [64], and now increasingly used to measure body ownership [65,66]), and electrodermal activity [67] to immunological alterations [68]. Such implicit measures may prove helpful in future clinical studies of a dissociation between body and self.

As mentioned in a recent review [69], some of these illusions have direct relevance for mentalizing and the construction of a shared space for social interactions. Putting oneself into the shoes of others requires to mentally locate oneself out of one's body and take the other's perspective. In fact, the implications of perspective taking may even be much broader than commonly assumed. It has long been known that the point of view of personal memories depends on affective valence: we tend to remember a refreshing running exercise from a 'within-body' perspective, while running away from a threat is rather remembered from a detached, 'out-of-body' perspective [70]. Bergouignan *et al*. [53▪▪] measured the quality of participants' memory for details of a conversation held once while their bodily self was felt in a regular within-body location and once while they faced the conversational partner after induction of an out-of-body illusion [47]. Intriguingly, participants' episodic retrieval was worse for the out-of-body perspective, which was accompanied by a reduced activation of the left hippocampus. This elegant study shows that paradigms originally created for the study of the bodily self can be exploited for investigations of a wider area of cognitive functions (see Table 1 for other, similarly broad explorations). On a conceptual level, it illustrates that memory retrieval has a strong embodied component (whose structural hub may be the right precuneus: [71▪]). Clinically, the findings may turn out to be relevant for developing treatment methods for memory problems in dissociative disorders, posttraumatic stress disorder and related amnestic

Table 1. Prominent experimental paradigms to investigate the bodily self

Rubber hand illusion (RHI)	Synchronous stroking of the invisible real hand and a seen fake hand induces illusory ownership for the latter [33]	Variations of the illusion: Illusion based on visuo-cardiac synchrony [34▪] Illusion based on the mere expectation of touch RHI [35] Illusion induced by self-stroking [36] (modified after [37,38]) Illusion based on auditory-tactile synchrony ('Marble Hand Illusion' [39]) RHI in a special group of participants: RHI can restore tactile awareness after spinal cord injury [40] RHI is enhanced for patients with somatoparaphrenia [25,41] RHI correlates positively with body dissatisfaction in body dysmorphic disorder [42] RHI in monkeys alters properties of neurons in S1 and M1 [43▪▪] RHI in children (4–9 years old) reveals two processes to establish bodily self [44] Illusory body perception and higher cognition: RHI with an outgroup hand can change implicit biases towards this group [45]
Full body illusion (FBI)	Synchronous stroking of either the back [46] or the front body [47,48] and the corresponding point of a virtual avatar leads to illusory ownership for the latter	Variations of the illusion: Illusion based on visuo-cardiac synchrony [49▪] Illusion induced by self-stroking (in MRI environment [50▪]) Illusory body perception and higher cognition: Illusory identification with a smaller/taller body changes object size perception [51,52], with a child body also implicit trait associations [52] Illusory disembodied perspective alters the formation of episodic memory (and associated physiological activity) in the left hippocampus [53▪▪]
Enfacement effect	Synchronous stroking of the own face and the face of a person sitting in front of you leads to illusory self-identification with the latter (measured by increased self-attribution of morphed images) [54,55]	Variants of the illusion: A related illusion not involving stroking is the 'strange-face-illusion' in which prolonged inter-subjective gazing induces the perception of strange faces [56] RHI in a special group of participants: Enfacement illusion demonstrated in newborns (looking preference paradigm) [57] Illusory body perception and higher cognition: Strength of illusion depends on sympathy (defined by previous interactions) [20] Enfacement illusion facilitates emotion recognition [58]
Mapping self-aspects on body templates	Elaborating on [59], participants have to map certain aspects of the self (e.g. the self [60], certain body landmarks [61▪] or emotions [62])	The self is not localized at one, but rather at two places: one centred on the upper torso and one on the upper head [62] Even in healthy participants, the subjective body metric does not correspond to the metric of the physical body [63] Basic and complex emotions are systematically mapped onto specific body locations in a cross-culturally stable way [51]

syndromes in connection with emotionally disturbing autobiographic experiences.

BODY PERCEPTION FROM THE INSIDE OUT

There is an increasing attention to the interoceptive sense in the current literature. We think this is more than a transient fad, but a trend that will significantly contribute to our understanding of the nature of the self, especially in its interactions with the social environment. Interoception means more than the continuous monitoring of one's physiological condition. It is at the heart of a person's emotional life and her hedonic capacities. Influential theories of emotion have relied on the interoceptive sense, but the recent upsurge is more broadly motivated. It embraces neurological, psychological and social aspects of the bodily self. On the level of functional neuroanatomy, many contributions elucidate the role of the insula for the integration of interoception, exteroception and emotion processing [72], specifically with respect to the binding of body and self [73▪]. Psychologically, interoceptive awareness, that is the sensitivity to consciously monitor internal body signals, is now recognized as an important personality trait, though with acknowledged cultural variations [74]. It predicts,

for instance, the urge to imitate observed body movements [75] susceptibility to the loss of self-other boundaries [76] and the size of individuals' autonomic response to caress-like hand movements in peripersonal space [77▪]. These latter studies document the relevance of interoception for social neuroscience. Paradoxically, the very sense devoted to the control of an individual's inner milieu may turn out to be a window to other selves; a possible mediator are empathic, 'shared' emotions, arguably an ontogenetically very early form of social awareness [78]. What remains to be established are the links between interoception and the frontoparietal system of multisensory peripersonal space [79] on the one hand and the right parietal lobe representation of social distance [80] on the other hand. A further line of research to be developed is an integrative approach that unifies interoceptive and other 'private' senses such as proprioception and the vestibular sense. Anatomically, convergence zones of interoceptive and vestibular signals have been described at the brainstem level, but to our knowledge, there is no behavioural exploration yet of the interactions between interoceptive and vestibular processing. Despite the early recognition that the sense of space and balance is barely separable from the sense of having a body [81], the importance of the vestibular system for the bodily self has only recently been rediscovered (reviews in [82–84]). The vestibular system plays a key role in coding egocentric reference frames, modulating perspective taking [85] and promoting self-other distinction [82]. These characteristics make the vestibular system contribute in important ways to higher social cognition both in health and disease ([84,86,87] for reviews).

THE BODILY SELF IN SOCIAL INTERACTIONS

The clinical pictures of many neuropsychiatric disorders, though painted on a neurological canvas, are coloured with a paintbrush constrained by social norms. People suffering from anorexia may show reduced connectivity in extrastiate cortex [88] and, on the behavioural level, may erroneously conceive themselves too big to pass a regular doorway [89]. But individual manifestations of their eating disorder strongly depend on normative standards regarding the appearance of a healthy body and on the severity of individual dysfunctions in the processing of social stimuli [90]. Likewise, persons with body dysmorphic disorder may show abnormal neural network organization [91], but their suffering emerges, by definition, from a comparison of their own bodily appearance with that of conspecifics. A recent review of several phenomenologically distinct, biopsychosocially grounded disturbances of the bodily self proposed that one common denominator could be a vulnerability of right prefrontal cortex [92]. Depending on environmental and social factors, this vulnerability would lead to a preoccupation with one particular aspect pertaining to body and self. Although hard to be tested empirically, such a view avoids the pitfalls of missing the big picture by unilaterally concentrating on either brain or society. We have recently delineated the foundations of a social neuroscience of one particular disorder of the bodily self that tries to unify brain, mind and society [93]. A description of the condition is provided in the following section.

Body integrity identity disorder

BIID was defined as 'an unusual dysfunction in the development of one's fundamental sense of anatomical (body) identity' ([94], p. 919). Affected people typically report a feeling of 'overcompleteness' and desire amputation of one or more limbs. Evidence is accumulating that this desire is accompanied by structural and functional alterations in areas of the cortex known as core to the binding of body and self. Table 2 summarizes all empirical studies we are aware of published during the review period [95,96▪,97–99].

Although their results are compatible with the idea that BIID is primarily a disease of the brain [100], alternative approaches deserve more attention than they currently receive among neurologists and in the neuroscience community. An essay drawing on the concept of Merleau-Ponty's 'sexual schema' complains that most neurologically oriented empirical studies on BIID neglect the fact that for the vast majority of affected persons, the concept of amputation has a strong erotic connotation [101], thus presumably evocating shared body representations. In fact, the oversimplification of the rich symptom complex that BIID entails may help publishing a focal research finding, but represents a disservice to medical decision making and ultimately to the suffering of the persons concerned. Neurologists' fear that, as soon as symptoms of paraphilia or obsession are in the foreground, psychiatrists should rather be in charge, is unfounded. Apotemnophilia, the precursor label for BIID, is a paraphilia designating sexual arousal by amputations. The spatial adjacency of insula and SII for leg representation could account for the higher frequency (at least four-fold) of legs than arms as amputation target in BIID [96▪]. As 'the insula supports an integration of body and mind' ([102], p. 616), such observations could support an integration of neurologically and psychiatrically motivated approaches.

Table 2. Empirical group studies on body integrity identity disorder published during the review period (2013–2014)

Study (alphabetical order) and method	Studied population(s)	Major findings	Strengths and weaknesses
Bottini *et al.* [95], Facial emotion recognition and disgust ratings for pictures and verbally described disgust-arising situations	5 men with AD for one leg, 1 man with AD for both legs, 1 woman with AD for one arm. Control participants matched for sex, age and education	All BIID participants show normal emotional facial recognition and disgust ratings of verbally described scenes. Five men with unilateral AD showed lowered disgust ratings for images specifically depicting violations of the body envelope (i.e. amputations)	Strength: Multiple case study design (no mixing of different clinical manifestation of BIID) Weakness: Lowered disgust for amputees' depictions may simply reflect erotic component of BIID
Hilti *et al.* [96▪], Structural MRI and surface-based morphometry. Questionnaire on amputation desire, erotic connotation, pretending behavior. Psychiatric, neurological and comprehensive neuropsychological examination	13 men with BIID; 8 with AD for left leg, 2 with AD for right leg, 3 with AD for both legs. Control participants matched for sex, age handedness, footedness and education	No neurological or neuropsychological dysfunctions, minor psychiatric distinctive features disappear after removal of scale items reflecting body dissatisfaction. Right-hemisphere cortical thickness/and or surface area reduced in superior and inferior parietal lobule, SI, SII, anterior insula; increased left-hemisphere cortical surface area in inferior parietal lobule and SII. Individual surface area of inferior parietal lobule correlates negatively with strength of amputation desire	Strengths: Relatively large sample size; comprehensive clinical testing, first study of structural brain correlates of BIID Weakness: No whole-brain analysis; only parietal and insular cortex selected as regions of interest
Lenggenhager *et al.* [97], Assessments of feeling of estrangement for all four limbs before and after caloric vestibular stimulation	As in ref. [2], above	No changes in estrangement ratings nor in skin temperature after stimulation in either ear	Strength: Speculations about efficacy of caloric vestibular stimulation have been put to the test Weakness: Estrangement ratings may not adequately reflect limb-specific concerns in BIID
Oddo *et al.* [98], Psychometric assessment of psychopathological and personality characteristics and of coping strategies	15 men with BIID; 12 with AD for one leg, 2 for both legs (1 not specified)	BIID participants show slightly elevated depressiveness and anxiety compared with population norms Personality characteristics comprise high agreeableness and autonomy. Coping strategies are characterized by self-control and self-affirmation	Strength: Largest sample of persons with BIID in which personality features and coping strategies were assessed Weakness: Questionnaire data may have limited validity in a sample highly motivated to proof normality
van Dijk *et al.* [99]	5 men with BIID (2 with AD for left leg, 3 with AD for right leg) and 10 matched controls	Selectively for the affected limb BIID participants show reduced activity in left ventral premotor cortex to tactile stimulation and, irrespectively of the leg, a generally heightened activity to touch in a large somatorsensory network	Strength: First functional MRI study in BIID, tested cortical response to both motor execution and tactile stimulation Weakness: Small sample size; no comparison of touch proximal vs. distal of line of AD

AD, amputation desire; BIID, body integrity identity disorder.

More explicitly addressing social aspects, a recent essay [103] is based on the analysis of blogs posted during a period of more than 15 years on an Internet interaction forum for people with BIID. It reports findings that are important beyond sociology and should inform any neuropsychiatric approach to BIID. In a nutshell, the author's analysis (see also [104]) shows that, first, BIID is not confined to an 'overcompleteness' in body structure, but includes the desire to become paralyzed, blind or deaf. Such longing for a functional impairment has been described earlier [105] and is covered by the labels 'transableism' or 'transability' [103]. Second, over the years, an individual's constellation of symptoms is strongly shaped by the symptom constellation of others posting their blogs on the site and by the currently dominating view of BIID as expressed in social media. This reflects the famous 'looping effect' [106] that describes an interaction between the ways of classifying illnesses and the symptoms serving classification. Third, as reflected by inconsistencies in terminology [107], BIID is thus a condition 'under construction', that is it moves along a moving trajectory between human diversity (inclusion in Diagnostic and Statistical Manual of Mental Disorders (DSM-5) was debated, but rejected [108]) and mental illness, much like it happened for gender identity disorder (GID) some decades ago [109]. Neurological studies should attempt to meet these sociological concerns to fully accommodate the complexity of BIID, appreciating old wisdom about the bodily self as a social rather than an exclusively private phenomenon [1]. It is our hope that a social neuroscience view of bodily self-consciousness will not only assist in bridging the gaps between brain, mind and society but also diminish the divide between neurology and psychiatry [110].

CONCLUSION

The mutual interplay between clinical observation and experimental findings (derived, for instance, from illusion paradigms) has elucidated the multisensory nature of the bodily self. New developments in the field comprise the growing attention given to the interoceptive and vestibular senses in connection with the process of self-other distinction and the bodily self in a social context. This context plays a prominent role in certain neuropsychiatric disorders (e.g. BIID) and makes a social neuroscience view of the bodily self indispensable.

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Conflicts of interest

There are no conflicts of interest.

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This article challenges the proposed link between cortical reorganization and phantom pain. In an fMRI study, phantom pain was associated with maintained representation of the missing ('phantom') hand, as well as with preserved structure. Moreover, relationships between phantom pain and functional isolation of the deprived hand area from its counterpart (intact hand) suggest that the maintained representation is dysfunctional.

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This study reviews empirical work on the human mirror mechanism and motor cognition more broadly and delineates the way from bodily self to intersubjectivity. It argues that sensorimotor systems for interactions with the world around us were decoupled from the final motor pathway and, by exaptation, are now reused for apparently abstract cognitive functions including social communication.

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The authors tested the prediction, inherent to motor theories of action comprehension, that observed hand actions, compared with actions executed with other body parts, would be more difficult to grasp for a participant born without arms. As long as action stimuli were photographs or videos, the participant performed equally well as normally limbed observers. However, he showed a selective deficit for manual actions when these were shown in a degraded way (point-light displays). The experiment shows that the mere visual analysis of body form and motion is sufficient for action understanding and thus disproves motor theories of action comprehension.

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Moving both hands simultaneously induces 'coupling effects', that is mutual interference between the movement trajectories of the two hands. Hemiplegic patients, who misattributed ownership of their own paralyzed left upper limb (including its movements) to the examiner, had to draw either a circle or a cross with their functional hand. When the examiner simultaneously drew the noncorresponding symbol, bimanual coupling was observed in the patients, indicating that the visually observed movement was incorporated. Control experiments showed that the occurrence of bimanual coupling was specific to the presence of the delusionally altered bodily self.

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