



Review

Schizophrenia as a self-disorder

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ABSTRACT

The aim of this review is to describe the potential relationship between multisensory disintegration and self-disorders in schizophrenia spectrum disorders. Sensory processing impairments affecting multisensory integration have been demonstrated in schizophrenia. From a developmental perspective multisensory integration is considered to be crucial for normal self-experience. An impairment of multisensory integration is called 'perceptual incoherence'. We theorize that perceptual incoherence may evoke incoherent self-experiences including depersonalization, ambivalence, diminished sense of agency, and 'loosening of associations' between thoughts, feelings and actions that lie within the framework of 'self-disorders' as described by [Sass and Parnas \(2003\)](#). We postulate that subconscious attempts to restore perceptual coherence may induce hallucinations and delusions. Increased insight into mechanisms underlying 'self-disorders' may enhance our understanding of schizophrenia, improve recognition of early psychosis, and extend the range of therapeutic possibilities.

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1. Introduction

We perceive our environment and ourselves by all our sensory systems ([Critchley et al., 2004](#); [Gallagher, 2005](#); [Angelaki and Cullen, 2008](#); [Craig, 2008](#); [Bermúdez, 2011](#); [Gallese, and Sinigaglia, 2011](#); [Bremner et al., 2012](#); [Damasio, 2012](#)). The neurobiological process of organizing and processing sensory information for effective interaction within the environment is called 'multisensory integration', and evolves during maturation ([Rochat and Striano, 2002](#); [Lewis and Ramsay, 2004](#); [Ayres et al., 2005](#); [Bremner, et al., 2012](#); [Ghazanfar, 2012](#)). It is regarded as crucial for various aspects of normal self-experience: recognition of own body, actions, imagination, memory, and (emotional) awareness ([Gallagher, 2000](#); [Damasio, 2001](#); [Jeannerod, 2003](#); [Rainville et al., 2006](#); [Tsakiris et al., 2007](#); [Craig, 2008](#); [Vianna et al., 2009](#); [Bermúdez, 2011](#); [Damasio, 2012](#); [Prebble et al., 2012](#)).

Many impairments affecting multisensory integration have been demonstrated in schizophrenia ([Table 1](#)). We hypothesized that these sensory deficiencies and abnormal self-experiences in schizophrenia might be connected. The aim of this review is to explore research on self and self-disorders in schizophrenia from the perspective of

multisensory integration, in a developmental context. All sensory modalities, including 'interoception' and vestibular sense, are our study objects.

First we will outline the historical context. After specifying the concept of self we will provide a description of self-experience in healthy individuals from a developmental and multisensory perspective. Subsequently, we describe the relationship between self-disorders and perceptual incoherence and schizophrenia spectrum disorders. Finally, we propose a sensory model as to self-disorders that may lead to psychotic symptoms, and postulate that subconscious attempts to restore perceptual coherence may induce hallucinations and delusions.

2. Method

A PubMed literature search was performed to address two questions: *Are perceptual incoherence and self-disorders related in schizophrenia spectrum disorders? If so, how can we characterize the relationship between perceptual incoherence, self-disorders and psychotic symptoms?*

Our search used the following keywords: schizophrenia, self-disorders, body image, body awareness, self-awareness, self-other organization, imagination, olfactory sense, proprioception, vestibular sense, interoception, haptic sense, sensory integration, sensory processing, crossmodal, and development. Additional literature was retrieved via references. There were no limitations regarding year of publication, languages were limited to English, French, German and Dutch.

3. Historical context

Many prominent psychiatrists have shared the concept that schizophrenia is associated with disintegration of self. In Bleuler's terminology

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Table 1
An outline of sensory dysfunctions affecting multisensory integration in schizophrenia spectrum disorders. Sensory dysfunctions regarding almost all senses are associated with increased risk for schizophrenia. Sensory deficits have been demonstrated in schizophrenia (Sz), Capgras syndrome (Cpg) and Delusions of Control (DoC), in relatives of schizophrenic patients (Rel), schizotypic personality (StP), depersonalization disorder (DPD) and self-delusions caused by brain lesions (BL). The only sensory deficit that is *protective* for schizophrenia is congenital blindness, which is associated with compensatory *strengthening* of somatosensory processing.

Senses	Sensory deficit	Investigated subjects	Literature
Olfactory sense	Deviant olfactory experiences	Predictive: Sz, ps	Cascella et al. (2007), Kwapil et al. (1996)
	Olfactory functions, meta-analysis	Sz, StP	Moberg et al. (in press), Cohen et al. (2012)
	Structural impairments olfactory system	Sz	Turetsky et al. (2009), Moberg et al. (in press), Cascella et al. (2007)
Haptic sense	Sensitivity and processing	Sz, StP, Rel	Lenzenweger (2000) Chang and Lenzenweger (2004) Chang and Lenzenweger (2005)
	Altered self/other discrimination	Sz	Blakemore et al. (2000), Silverstein et al. (2012)
	Higher susceptibility for Rubber Hand Illusion	Sz	Thakkar et al. (2011), Peled et al. (2000)
Propriocepsis	Impaired sensory processing all cerebral levels	BL	Feinberg (2009)
	Lower processing speed/attenuated beta and gamma oscillations-proprioceptive info	Sz, StP	Arnfred et al. (2006), Arnfred et al. (2010)
	Recognition and prediction motor actions	Ps, Sz, DoC	Ferri et al. (2012), Franck et al. (2001) Frith et al. (2000), Frit (2005), Fourmeret et al. (2002), Jeannerod (2003), Shergill et al. (2005), Silverstein et al. (2012), Synofzik et al. (2010)
Vestibular sense	Eye tracking abnormalities	Sz	Jones and Pivik (1985), Levy et al. (2010), Pawlak-Osińska et al. (2000)
	Hypo-reactivity and dysfunction	Sz, HR-Sz	Colbert et al. (1959), Fish and Dixon (1978) Gordon (1979), Levy et al. (1983)
	Altered vestibular responses and synchrony	Sz, DPD	Haghgoie et al. (2009), Ornitz (1970), Sang et al. (2006)
	Visuo-vestibular disintegration	Sz, StP	Schilder (1933), Pawlak-Osińska et al. (2000)
	Caloric vestibular nerve stimulation is beneficial	Sz, BL	Levine et al. (2011), Lopez et al. (2012), Rubens (1985)
Interoception	Autonomic abn. & disconnection response	DPD, Sz, Cpg	Dawson et al., (2010), Lewis et al. (2001), Ellis and Lewis (2001), Roux et al. (2010), Williams et al. (2007)
	Simult. co-activation two evaluative systems	Sz	Trémeau et al. (2009)
	Interoception related to emotion processing	Sz, DPD	Seth et al. (2011), Wylie (2010)
	Pain processing and monitoring	Sz Rel	Josephus Jitta (2012), Kring and Neale (1996), Potvin and Marchand (2008), Shintani (2010), Singh et al. (2006)
Audio-visual	Hearing or visual dysfunction	Higher risk: Sz	Butler and Javitt (2005), Butler et al. (2009), Chen et al. (2003), Chen (2011), Coleman et al. (2009), Javitt (2009), de Jong et al. (2009), de Gelder et al. (2005)
	Congenital blindness is protective for Sz	Sz	Silverstein et al. (2006), Silverstein et al. (2012)
	Visual processing	Sz	Butler and Javitt (2005)
	Auditory processing	Sz	Micoulaud-Franchi et al. (2012, 2011), Leitman et al. (2008)
	Audio-visual processing	Sz	de Jong et al. (2009), Ross et al. (2007)

'splitting of the psyche' or 'loosening of associations' is manifested in, ambivalence, inappropriate or flattened affectivity and autism (Bleuler, 1911; Moskowitz and Heim, 2011). Some psychiatrists linked sensory dysfunction with disturbance of self in schizophrenia (Pick, 1904; Schilder, 1933; Blankenburg, 1971; Mahler and McDevitt, 1982). Schilder (1933) related sensory disintegration to disintegration of the ego directly, and assigned a special role for the vestibular apparatus.

Various investigators observed disturbance of sensory integration and vestibular pathology in childhood and adult schizophrenia (Colbert et al., 1959; Ornitz, 1970; Ayres, 1972; Jorstad et al., 1977; Fish and Dixon, 1978; Gordon, 1979; Blakeney et al., 1983; Levy et al., 1983; Jones and Pivik, 1985; Fish and Kendler, 2005). Blankenburg's investigations led to what he regarded as the core phenomenon of schizophrenia: "der Verlust der natürliche Selbstverständlichkeit", literally translated 'the loss of natural self-evidence', in English literature often referred to as 'a loss of common sense' (Blankenburg, 1971; Uhlhaas and Mishara, 2007).

After the rise of the Diagnostic and Statistical Manual of Mental Disorders (DSM), the influence of the abstract concept of self and the concept of sensory integration both declined. DSM fulfilled a need for objectivity and scientific verification. Against the grain, phenomenological studies continued in Europe (Huber, 1995; Klosterkötter et al., 1997; Parnas, 1999). Sass and Parnas (2001, 2003) introduced a phenomenological model, which relates self-disorders to positive and negative symptoms and disorganisation.

Damasio (2001) offered another perspective: patterns of sensory information, especially 'interoception' (i.e. the sensing of the organism's interior) lead to awareness of emotions.

By now, phenomenological ideas are welcomed again as a valuable approach in the area of early detection and prevention of psychosis (Nelson et al., 2012) and the subject of sensory integration in schizophrenia gains in interest rapidly (Javitt, 2009).

4. Development of self

For pragmatic reasons we describe normal sense of self as a feeling of unitary entity, the "I", that owns and authors its thoughts, emotions, body and actions. The development of a sense of self is intertwined with the developmental abilities to integrate sensory input (Rochat and Striano, 2002; Lewis and Ramsay, 2004; Rochat, 2011b; Bremner et al., 2012). Though the environment continuously influences us, we are demarcated from it (Kuiper, 1986; Gallagher, 2000; Kircher and David, 2003). Multisensory input continuously informs us, which is essential for normal self-experience (Gallagher, 2005; Zahavi, 2005; Craig, 2010; Gallese and Sinigaglia, 2011; Blanke, 2012; Damasio, 2012). Like our nose is always present in the centre of our visual field, a 'background composition of multisensory input', responsible for an abstract awareness of ourselves, is present in every experience we have (Table 2). This 'sensory self' is analogous to phenomenological concepts as 'presence', 'core self', 'minimal self' or 'ipseity' (Sass and Parnas, 2003; Stanghellini, 2004; Gallagher, 2005; Cermolacce et al., 2007; Bermúdez, 2011; Damasio, 2012).

Normal development of self requires increasing skills to reach agreement between different perspectives of self, in different situations, without a gross distortion of reality. Neurological and phenomenological self-development is intertwined, has analogous hierarchical composition, and is consistent with developmental milestones.

In the first months after birth, information from the inner body and physical boundaries is dominant (Rochat, 2001; Rochat and Striano, 2002; Feinberg, 2009; Rochat, 2011a,b; Bremner et al., 2012). Newborns appear to have a sense of being embodied in an environment in which they have agency (Rochat, 2011a). This minimal self-awareness is infused with meaning arising from interaction with others (Mahler and McDevitt, 1982; Aitken and Trevarthen, 1997; Rochat, 2001; Rochat and Striano, 2002; Rochat, 2011a). In infancy (0–12 months),

Table 2

The senses, their associated functions and contributions to normal experience. Body-centred senses (especially olfaction, haptic and vestibular sense) develop earlier than environment-oriented senses (a simplified representation, crossmodal interactions have been omitted).

Sense	Associated functions	Normal experiences	Literature
Olfactory	<ul style="list-style-type: none"> –Digestive behaviour –Familiarity–unfamiliarity –Orientation –Infant emotion regulation –Attachment & social functioning –Emotions–Learning–Memories–imagination 	<ul style="list-style-type: none"> –Many smells are unaware. –Smells bring forth memories or associations and influence emotions. –Food, family and home environment smell familiar. Familiar smells cause relaxation and rapprochement. –Smelling occurs by inhalation into the body. Unusual smells cause vigilance/aversive smells feel intrusive and bring forth strong self-protective behaviours. 	Bremner et al. (2012), La Buissonnière-Ariza et al. (2012), Damasio (2012), Kivity et al. (2009), Schaal and Durand (2012), Stevenson (2010)
Haptic	<ul style="list-style-type: none"> –Perceiving superficial touch –Perceiving shape and texture –Demarcation body segments –Position of body parts –Physical boundary –Body image/ownership –Infant emotion regulation –Attachment 	<ul style="list-style-type: none"> –My skin encloses my body, forms a boundary between inner and outer world. –My inner body is private and cannot diffuse into the outer world; it is inaccessible from the outer world. –Skin sensations mirror my presence, position and adjacent surroundings. –Touch influences relational contacts. 	Aspell et al. (2009), Bermúdez (2011), Bremner et al. (2012), Cole and Paillard (1995), Duhn (2010), Ernst (2002), Feinberg (2009), Ferrè (2011), Gallagher (2005), Hohwy and Paton (2010), Rochat (2011a, 2011b), Schütz-Bosbach et al. (2009), Tsakiris et al. (2007, 2011), de Vignemont et al. (2009)
Vestibular	<ul style="list-style-type: none"> –Coordination eyes & body movement –Integration interoception and exteroception –Differentiation of active vs. passive –Orientation in place and person –Integration actions, cognitive efforts, autonomous nervous system& limbic system 	<ul style="list-style-type: none"> Vestibular activity evokes no conscious sensations –My body is in balance. –Gravity pulls me towards the ground. –I am here, confined to my body. –Stable unity between ‘me’, my mind, my body, emotions, actions and environment. 	Angelaki and Cullen (2008), Bermúdez (2011), Blanke and Arzy (2005), Carmona et al. (2009), Cheyne and Girard (2009), Ferrè et al. (2011), Fetsch et al. (2009), Giummarra et al. (2008), Jáuregui-Renaud et al. (2008), Lopez et al. (2008, 2010, 2012), DeAngelis and Angelaki, 2009., Rochat (2011a, 2011b), Schilder (1933), Sang et al. (2006)
Interoception	<ul style="list-style-type: none"> –Pain perception –Implicit awareness of inner physical fluctuations –Interpersonal attunement –Embodied simulation –Self-other discrimination –Motivation –Orientation in time 	<ul style="list-style-type: none"> –Damage of my body hurts. –I’m aware of my and other’s emotions. –I can separate my own from other’s emotions. –I can distinguish reality from dreams, memory and imagination. –My actions are largely driven by inner motivation. –My feelings vary along with actions and events I go through. –My body and mind are united. –Time feels continuous. I am in the present, between past and future. –My body is a solid entity. 	Bechara and Naqvi (2004), Buccino and Amore (2008), Carmona et al. (2009), Craig (2008), Critchley et al. (2004), Damasio (2012), Gallese et al. (2007), Gallagher (2005), Giummarra et al. (2008), Perl (2007), Potvin and Marchand (2008), Tsakiris et al. (2011)
Proprioception	<ul style="list-style-type: none"> –Motion-perception –Deep pressure –Position joints/body parts –Union of body parts to motor units –Posture –Spatial orientation –Self-other differentiation 	<ul style="list-style-type: none"> –Movements strengthen my bodily awareness, but bodily attention is not needed for everyday actions. –I am aware of my intentions and execution of actions, without taking notice of the process. 	Bermúdez (2011), Bremner et al. (2012), Cole and Paillard (1995), Ehrsson et al. (2005), Ernst and Bühlhoff (2004), Feinberg (2009), Gallagher (2005), Gallese and Sinigaglia (2011), Giummarra et al. (2008), Rochat (2011a, 2011b), Tsakiris et al. (2007, 2011)
Environment orientated: Auditory & visual sense	<ul style="list-style-type: none"> –Extero-sensory confirmation of somatosensory perspective 	<ul style="list-style-type: none"> –I am here, in the centre of my experiential world. –My body is demarcated from the environment. –My body image resembles my features in the mirror. 	Aspell et al. (2009), Bremner et al. (2012), Damasio (2012), Ernst and Banks (2002), Gallese and Sinigaglia (2011), Giummarra et al. (2008), Kernberg et al. (2007)

interaction enhances and environmental information is increasingly important (Ayres et al., 2005; Feinberg, 2009; Ghazanfar, 2012). Interplay between visual, auditory and somatosensory information becomes more dynamical. Between 1 and 6 years of age, modulation of impact given to vision and proprioception plays a role in fine-tuning of body representations (Bremner et al., 2012). Observed behaviour of others is used as a mirror to gain knowledge about self and others (Gallese, 2003). A strong self-evaluating system and sense of self-constancy develops. A child of 21 months is able to recognise himself, i.e. to integrate different self-perspectives: felt from the inside (first person perspective) and from the other’s point of view (third-person perspective) (Rochat and Striano, 2002; Lewis and Ramsay, 2004; Rochat, 2011b). Simulation of others’ behaviours, including ‘embodied simulation’ (i.e. a perceptive bond between subject and object), precedes the ability to think about other persons’ thoughts and imagine others’ mental experience (Gallese, 2003). This latter ability is presumed to develop from 5 years of age and contributes to Theory of Mind (TOM, third person perspective), and the ability to predict other’s actions (Rochat, 2001; Lewis and Ramsay, 2004; Rochat, 2011b; Damasio, 2012). Coherent reality monitoring is not yet achieved at this age (Dehart et al., 2004). A

further refinement of skills in middle and late childhood (6–12 years) is associated with optimal sensory integration (Ernst, 2008; Bremner et al., 2012), increasing sense of self-continuity and sense of agency, but also for potential false-self behaviour (Dehart et al., 2004; Harter, 2012). Increasing metacognitive understanding and logical reasoning go along with growing reality-monitoring abilities (Dehart et al., 2004). In adolescence (10–18 years), cortical remodelling and enhanced efficiency and fidelity of signal transmission (Tau and Peterson, 2009) go along with self-differentiation: identity formation, improving coping strategies, and reality monitoring. As adolescence progresses, ambivalent facets of self can be united (Dehart et al., 2004; Harter, 2012).

5. Multisensory integration

‘Multisensory integration’ refers to the integrating process involving all senses. This process starts with detection of sensory input by modality-specific receptors that translate stimuli (light, sound, chemical, mechanical and temperature) to neural activity. The resulting mental impression of distal stimuli is perceived as a confluent whole, the

'percept' (Ernst and Bühlhoff, 2004; Ayres et al., 2005; Lou et al., 2010). Within this percept, relations between different modalities change from moment to moment. For example, selective attention can reduce sensory integration by inhibiting input from other senses. Similarly, the level of *attention* influences the *composition and cohesion* between background and foreground information (Bahrick and Lickliter, 2012; Laurienti and Hugenschmidt, 2012). Although the input of all sensory modalities is merged, a differentiation between their sources (f.e. inside or outside) is necessary for the ability to distinguish between self and non-self and between imagination and reality (Brébion et al., 2002; Feinberg, 2009; Ferchiou et al., 2010; Gawęda et al., 2013). Specific properties of different modalities contribute to a paradox within the self: both discrimination and unity must be achieved, not only between self and environment, but also between different facets *inside* the self (Table 2).

Discrimination between self and non-self and sense of boundaries is offered by proprioception and touch (Ramachandran and Hirstein, 1998; Feinberg, 2009; Miyazaki et al., 2010; Tsakiris, 2010). Tactile sensations form a continuous "sensory sheet" covering the whole body (de Vignemont et al., 2009): a pivotal position for giving shape to physical boundaries.

All senses contribute to a normal sense of self (Table 2). Regarding the tacit nature and incoherent characteristics of self-disturbances, we argue that if multisensory integration is affected in self-disorders, probably nondescript senses with strong integrative effects are involved, such as vestibular sense and interoception (Angelaki and Cullen, 2008; Bermúdez, 2011; Lopez et al., 2008; Tsakiris et al., 2011).

'Interoception' provides perception of inner movements ('feeling of feelings'): the basis for the emotional awareness and representation of the body from within (Damasio, 2012). It is assumed that interoception is not only involved in emotional attunement to the environment, but also in distinction between one's own and the others' emotions (Bechara and Naqvi, 2004; Critchley et al., 2004; Gallese et al., 2007; Murata and Ishida, 2007; Buccino and Amore, 2008; Berlucchi and Aglioti, 2010; Craig, 2010; Bermúdez, 2011; Tsakiris et al., 2011; Damasio, 2012). Distinction and attunement between self and others enable engagement in social interactions.

Vestibular signals contribute to most everyday behaviours yet produce no conscious sensations (Ferrè et al., 2013). The vestibular system integrates vestibular, body-centred and environment-oriented input. Vestibular disturbances result in disintegration of sensory input and extreme experiential changes that are distressing and feel weird. The vestibular system occupies a pivotal position at the crossroads between physical, mental and emotional homeostasis (Angelaki and Cullen, 2008; Lopez et al., 2008; Carmona et al., 2009; Cheyne and Girard, 2009; Bermúdez, 2011).

6. Perceptual incoherence

An impairment of multisensory integration is called 'perceptual incoherence'. Perceptual incoherence can be induced by contradictory sensory input or extreme imbalance between various types of sensory input, which result from local or generalized decreased somatosensory feedback or sensory-motor contradictions to such an extent that information cannot be united as one percept. It has been demonstrated that incoherent sensory information brings forth incoherent experiences.

Perceptual incoherence may occur in non-pathological situations, such as when we erroneously expect another step on top of the stairs: the foot sinks through the imagined step. A startling change of forces in foot, muscles and joints, gravity and momentum increases risk of falling (Bakken et al., 2007). A startle response, a sinking feeling in our stomach as if in a roller coaster, and disorientation occur until we reflexively regain our feet and feelings. Other examples: the short moment we perceive (feel) our train is departing in the wrong direction, until we realise (see) that – in fact – another train is moving (Ernst and Bühlhoff, 2004). In case of local anaesthesia, incoherence persists until

the effect of the anaesthetic wears off. In all these cases incoherence is comprehensible and resolves easily, which considerably attenuates feelings of anxiety and surprise.

To show what mechanisms might be effective in reducing perceptual incoherence, we will give some examples, that later on will be discussed concerning self-disorders and hallucinatory experiences. Conflicting sensory information is associated with persistent phantom limb sensations in amputees, e.g. consisting of sensory and motor memories (Ramachandran and Hirstein, 1998). Also, sensory internalization of environment-oriented input in the phantom limb can occur: If amputees look at the stroking of someone else's arm, visual information is transformed into haptic experiences upon one's corresponding phantom limb (Ramachandran and Brang, 2009). This internalization of environment-oriented input attenuates unpleasant sensations in the phantom limb. 'Alexithymia' causes incoherence between emotional state and feelings, for example when a person feels tears in his eyes, without being able to trace these tears to sadness. Alexithymia and concomitant hypochondria are associated with 'somatosensory amplification', a sensory process in which impact of (normal) sensations increase due to preoccupation and concomitant reduction of self-awareness (Mailloux and Brener, 2002; Nakao et al., 2002; Helling, 2009).

In healthy subjects, sensory manipulation can bring forth perceptual incoherence that results in profound alterations of self-experience in healthy subjects (Blanke, 2012). Asymmetrical vestibular stimulation can induce incoherent phenomena that can be reckoned among self-disorders (depersonalisation, derealisation, disturbances of body ownership) and hallucinations (Schilder, 1933; Kolev, 1995; Sang et al., 2006; Lopez et al., 2008; Cheyne and Girard, 2009). Experiences can be induced of being touched on a rubber hand, of experience of touch by alleged 'supernatural causation', or experience of alleged 'body transfer' (Hohwy and Paton, 2010; Slater et al., 2010; Tsakiris, 2010; Tsakiris et al., 2011; Bouchard et al., 2012).

7. Self-disorders

Self-disorders are pervasive and enduring anomalies of experienced self. They are often present long before the first psychotic episode and may also occur in other disorders. Self-disorders can be predictive for psychosis onset (Nelson et al., 2012), and occur in all following stages of schizophrenia (Schultze-Lutter et al., 2010; Parnas et al., 2011). Related concepts are 'Abnormal Subjective Experiences' (ASE) and 'Basic Symptoms' (BS) (Klosterkötter et al., 1997; Parnas et al., 2005; Schultze-Lutter et al., 2010; Stanghellini and Ballerini, 2011; Stanghellini and Fusar-Poli, 2012).

Self-disorders consist of two interdependent components: 'diminished presence' and 'hyperreflexivity' or 'perplexity'.

'Diminished presence' is a phenomenological term for an alienating experiential state in which a patient does not (entirely) feel vital or present in this world (Sass and Parnas, 2003). Diminished presence can be experienced in several ways: a sense of being dissolved or to fall apart, a profound lack of identity, permeable or blurred boundaries of the body, and not feeling related to own experiences or to the environment. In the cognitive domain, 'diminished presence' can be revealed as thoughts that seem to appear automatically, not to be produced by one's self. The latter phenomena are usually accompanied by profound ambivalence. In search for explanation these experiences often lead to existential thoughts (Sass and Parnas, 2003; Parnas et al., 2005, 2011; Stanghellini and Fusar-Poli, 2012; de Vries et al., 2013).

'Hyperreflexivity' or 'perplexity' is a puzzled state characterized by hyper-alert monitoring the qualitative changes of (inner) life. Inner processes such as thinking, perceiving or moving that normally occur implicitly without much conscious thought, now become tasks that need to be guided and controlled in a mechanical way (Stanghellini, 2004). This hyperreflexivity goes along with concomitant decline of usual clearness in the field of awareness (Raballo and Parnas, 2011). A

loosening between the point of focus and context, lead to profound experiential changes in which front and background perceptions within the field of awareness have been exchanged (Stanghellini, 2004; de Vries et al., 2013). The patient is attempting to accommodate this anomalous experience to existing schemas. This is reflected by frequent preoccupations with philosophical, supernatural, and metaphysical feelings of centrality or solipsism (Sass and Parnas, 2003).

8. Schizophrenia

Schizophrenia is often preceded by sub-delusional detachment from reality that can be regarded as manifestation of self-disorders (Schultze-Lutter et al., 2010; Parnas et al., 2011; Nelson et al., 2012) or as perceptual incoherence. In schizophrenia, self-recognition and self-other discrimination are impaired by defects in several multisensory mechanisms: reduced recognition of the body, impaired emotion-processing, abated authorship, disintegration of sensory input, and impaired source discrimination (Bender et al., 2007; Murata and Ishida, 2007; Uhlhaas et al., 2008; Roux et al., 2010). ‘Diminished presence’ may result from deficits in somatosensory feedback, which undermine the perceived sensory self (Table 1). Proprioception and tactile sensations are essential for sense of action and boundaries. Self-other discrimination strongly depends on discrimination between internal and external sensory inputs (Blakemore et al., 2000; Thakkar et al., 2011). Reduced source discrimination (e.g. misattribution of own actions to others) can be provoked by reduced boundary recognition (Tsakiris, 2010) due to reduced haptic sense or proprioception. Impaired self-monitoring and source monitoring have been found to correlate with auditory hallucinations, thought intrusion and alien control symptoms (Blakemore et al., 2000; Chang and Lenzenweger, 2005; Ferchiou et al., 2010; Synofzik et al., 2010; Waters and Badcock, 2010; Waters et al., 2012; Gawęda et al., 2013). In sum, depending on which somatosensory feedback is impaired, perceptual incoherence may cause depersonalization, blurred boundaries, cenesthopathies and/or diminished sense of

ownership and agency (Table 3). In all these manifestations diminished self-perception is analogous to ‘diminished presence’ (Sass and Parnas, 2003; Cermolacce et al., 2007; Gallagher, 2005).

When hearing or vision is impaired, risk for schizophrenia is higher (Butler and Javitt, 2005; Schubert et al., 2005; Schiffman et al., 2006; Silverstein et al., 2006; Senkowski et al., 2007; Javitt, 2009; Chen, 2011; van der Werf et al., 2011; Silverstein et al., 2012). In schizophrenia (without evident impairment of hearing or vision), many audio-visual integration disturbances have been demonstrated. Congenital blindness however, seems to protect against schizophrenia, though not to mental illness in general. This protection is associated with compensatory superior perceptual abilities of body-centred senses. These findings strengthen the idea that disabled sensory integration or diminution of somatosensory feedback may undermine self-awareness in schizophrenia.

We will focus further on vestibular sense and interoception. The vestibular system is crucial for multisensory balance and multisensory integration. Vestibular dysfunction, visuo-vestibular disintegration and reduced functional connectivity between vestibular neural centres have all been demonstrated in schizophrenia (Schilder, 1933; Fish and Dixon, 1978; Gordon, 1979; Levy et al., 1983; Jones and Pivik, 1985; Levy et al., 1994; Pawlak-Osińska et al., 2000; Haghgoeie et al., 2009; Chen, 2011). Caloric left vestibular nerve stimulation induced a short-lived beneficial effect on specific types of illness denial and delusions in schizophrenia, and improved ownership of body parts in neurological patients (Lopez et al., 2010; Levine et al., 2011).

Impairment of emotion-response may be regarded as one of the manifestations of disturbed *interoception* in schizophrenia. Inadequacy of affect in schizophrenia is associated with several phenomena, such as: anticipatory pleasure deficit, blunted responses to emotional stimuli, and impaired expressiveness of facial musculature and emotion-processing disturbances (Kring and Moran, 2008; Trémeau et al., 2009; Dowd and Barch, 2010; Strauss, 2013). In schizophrenia, alexithymia has been related to impaired interoception (Kubota et al.,

Table 3

Self-disorders consist of interrelated ‘diminished presence’ and ‘hyperreflexivity’; these phenomena show analogies to several multisensory integration deficits. Sensory deficits and multisensory impairments may explain phenomenological experiences: diminished somatosensory feedback seems analogous to diminished presence, preoccupation-induced somatosensory amplification seems analogous to hyperreflexivity. The resultant sensory contextual loosening seems to go hand in hand with changes in the perceptual composition, in which hyperawareness to some background processes (as thinking, perceiving or moving) is coexistent with a decline of the usual clearness in the field of awareness. The experience changes in a profound and ‘inexplicable’ way.

Verbal expressions by patients	Self-disorders	Hypothetical sensory deficit
“Losing sense of being me, not being able to make sense of what happens to me, being unable to connect with others, makes me feel inhumane”.	Diminished self-presence Diminished sense of basic self Self-alienation	Reduced interoception
“I think I am dissolving”.	Bodily disintegration	Waning ‘sensory self’. Haptic sense, proprioception, interoception
“It felt as if it turned inside my head ... when my eyes were directed at one point, than I suffered least from this extra-terrestrial feeling”.	Cenesthopathies	Vestibular dysfunction
“I know it’s my body and face, but it doesn’t feel this way. It’s scary”.	Somatic depersonalization	Reduced proprioception, interoception
“The body does it, but I’m not in it”.		
“I know they are my thoughts, but I do not feel they’re mine”.	Distorted first-person perspective Loss of thought ipseity	Dissociation thoughts and interoception
“Some thoughts, I cannot decide whether they should be there”.	Hyperreflexivity	Disintegration thought and interoception.
“Thinking went in too many directions in the same time. I couldn’t decide what to do, unless I was forced to”.	Thought pressure	
“I could not go one direction, everything was even. I stayed in one big soup”.	Ambivalence	Reduced interoception leads to diminished connection to inner and outer world
“I felt like death, feelings were absent. I felt like in a mist, nothing had any significance”.	Ambivalence Melancholiform depersonalization Diminished vitality	
“If people touch me, it seems like they come through my skin”.	Reduced transparency of awareness	
“I saw a bird flying. It flew into my belly and made a nest in my spine”.	Diminished demarcation Cenesthetic experiences	Diminished haptic sense, proprioception, interoception > reduced source discrimination external/internal info
He experienced that his thoughts ran onto his skull and even came out of his head (like the box of Pandora). His thoughts bounced onto the ceiling. He knew that this could not be true.	Hyperreflexivity	Reduced interoception leads to diminished connection to thoughts
“It feels as if I’m only my legs”.	Thought pressure	
“My soul is in my heels, every step I take, I step on it”.	Spatialization of experience, concretisms Morphological change Psycho-physical misfit	Somatosensory deficit > body image or perceived mind/soul/spirit is incongruent with anatomical/biological characteristics
“I’m looking for arguments to make sense. Nothing has a meaning or purpose”.	Loss of common sense	Loss of sensory context

2012). Other indications for disturbed interoception are disconnection between central and autonomic system for processing signals of danger (Williams et al., 2007), and dissociation between explicit and implicit processing of prosody¹ (Roux et al., 2010). An intriguing example is the deficiency of autonomic responses in Capgras syndrome, which is assumed to impair recognition of familiar faces and voices. This leads to delusional beliefs that familiar persons are impostors (Lewis et al., 2001; Ellis and Lewis, 2001). Pain perception is another manifestation of interoception; its impairment is a notorious pitfall in somatic diagnostics in schizophrenia patients (Josephus Jitta, 2012; Potvin and Marchand, 2008; Singh et al., 2006). The insula is a brain region where interoception, and body-centred and environment-oriented input are processed. In schizophrenia the insula shows neuro-anatomical and functional abnormalities that correspond to disrupted interoception processing (Wylie and Tregellas, 2010).

9. Discussion

The idea that schizophrenia is associated with multisensory impairments has been suggested earlier. We propose a model in which perceptual incoherence is linked with self-disorders in schizophrenia. The mechanism described here is in concert with a meta-analysis of neuropsychological experiments in which Waters et al. (2012) concluded: *'Self-recognition is impaired in patients with schizophrenia and particularly those with auditory hallucinations. This suggests an association, perhaps a causal one, between such deficit and hallucinatory experiences in schizophrenia'*.

One of the reasons that bottom-up influences are still underrepresented in scientific literature may be the implicit nature of sensory integration disturbances. The interplay between top-down and bottom-up processes is however evident (Adcock et al., 2009; Silverstein et al., 2012). Many mechanisms investigated from various perspectives, support our hypothesis: disturbances of neural synchrony and reduced NMDA neurotransmission (Uhlhaas et al., 2008; Woo et al., 2010), dysconnectivity and plasticity (Stephan et al., 2009), changes in brain architecture involved in self-processes (Wylie and Tregellas, 2010; Guo et al., 2012), cognitive dissonance theory (Festinger, 1957; van Veen et al., 2009), aberrant salience (Kapur, 2003), social defeat hypothesis (Selten and Cantor-Grae, 2005), and psychodynamic theories in which is surmised that psychosis can be explained as an attempt to restore the defective 'self' (Kohut and Wolfe, 1978; Schore, 2009).

Normal self-experience relies on a coherent percept. The human brain regularly receives ambiguous sensory information and has capabilities to resolve these situations (Ernst and Bühlhoff, 2004; Roach et al., 2006). We argue that the disorder of the self in schizophrenia is due to perceptual incoherence. Coping strategies may alleviate incoherent sensory experiences on the expense of reality monitoring, and thereby induce psychosis according to the following hypothesis:

Conflicting sensory input results in sensory ambivalence, expressed in a qualitative change of experience of unknown origin. This state captivates attention. The object of focus is often aimed at internal processes (thoughts, perceptions, feelings, actions). A preoccupied focus generally leads to loosening of the focused object from its sensory context (i.e. disintegration) on the one hand, and causes sensory amplification (i.e. increased impact) on the other hand. This sensory 'bootstrap' can change impact and salience of any thought or sensory detail. Simultaneously reduced attention for other meaningful events is analogous to a decline of the 'usual clearness of the field of awareness' (Raballo and Parnas, 2011). Sensory imbalance obstructs integration of sensory input to one unified percept. A perpetual circle of (focal) reduced sensory input, hyper-focused attention, sensory amplification and

subsequent disintegration might take hold of the experiential world. In this circle reduced sensory input is analogous to 'diminished presence' and hyper-focused attention is analogous to 'hyperreflexivity' in phenomenological terms. This results in *diminished cohesion* and an *altered composition* between background and foreground sensory information, which changes subjective experience in a profound and 'inexplicable' way (de Vries et al., 2013).

Two examples: perceptual incoherence emerges if interoception in a certain situation is dissonant with the predicted somatosensory pattern. If one does not feel a pounding heartbeat in anxiety or thrill in enthusiasm, the 'colour' of experiences is qualitatively changed. Due to this incoherence between the experience from the inner body and environmental occurrences, emotions seem blunt, the surrounding world feels strange, and self may even feel inhuman.

Similarly, thoughts with emotional impact deprived from predicted interoception, create experienced distance to one's thoughts: thoughts seem unfamiliar or automatic or seem not to be produced by oneself. Apart from experienced alienation from one's thoughts, the vanished inner sensory point of reference (Bermúdez, 2000), results in a compromised inner dialogue in which it seems as if the 'I' is not involved. This prevents adopting a clear position: opposing ideas and intentions seem to interrupt each other, and generate crippling ambivalence. Intense reflection about chaotic thought-processes might increase their impact and bring further dissociation between thoughts and their emotional contents. This is how incoherence between thoughts and interoception might contribute to an experience of being 'disembodied'. Concomitant sensations e.g. caused by stress (twitches, headaches etc.) may increase to strange experiences such as buzzing sensations or a feeling as if the head will explode. If these sensations cannot be linked to stress, but instead are integrated with the changed quality of thought-content, this might lead to concretization of thoughts (Table 3).

Furthermore, if experiences are deprived of aligning somatosensory feedback, then engagement in thinking and activities will increase perceptual incoherence, which might result in avoidance. Avoidance may be effective in the short term, but increases inner absorption, ultimately leading to further distance between inner and outer world. This sensory mechanism can explain reduced feelings of purpose, disorganisation, retreat into one's inner world, avolition, a sense of misalignment or disconnection between mind and physical 'self'.

Uncanny sensory experiences might lead to 'unintelligible' behavioural changes, aimed to increase feelings of safety (even before reality monitoring has been overthrown): avoiding direct eye-contact, protecting the body's boundaries, closing the curtains, using cannabis, or demanding medical investigations.

Any somatosensory deficit resulting in perceptual incoherence may function as a 'sensory vacuum' in the sensory self. To resolve perceptual incoherence, the brain can create experiences (imagination) or retrieve sensory surrogates from other mental domains (memories or thoughts that do occur with pertained emotions) and fill the sensory vacuum. For example, diminished somatosensory feedback results in diminished self-recognition expressed in a sinister feeling that 'something' is wrong. In search for explanations, subsequent preoccupation results in sensory amplification of normal background sensations to extraordinary proportions. Some become preoccupied with the idea of an imaginary disease, others might become anxious about environmental threats or seek refuge in magical ideation. Top-down enhanced sensations or retrieved sensations from other mental domains (dreams, imagination, memory, internalization) may then fill the sensory vacuum. A relief caused by attenuation of perceptual incoherence might cause an intuitive feeling as if these explanations 'fit' and create a fixed sense of reality, such as a caricatured body image, personal threat, or some prophecy. Thus, sensory congruence will be restored at the expense of diminished reality monitoring. From this perspective, delusions and hallucinations can be regarded as a 'solution' for incomprehensible, incoherent multisensory experiences.

¹ Prosody is implicit intonation-recognition, which is necessary for grasping the emotional colour of language.

10. Conclusion

Somatosensory feedback is a fundamental mechanism to important aspects underlying self-recognition such as sensory–motor prediction, imagination and memory. Impaired somatosensory feedback may lead to perceptual incoherence. ‘Perceptual incoherence’ is analogous to incoherent self-experiences described as ‘self-disorders’ by Sass and Parnas, the ‘loosening of associations’ between thoughts, feelings and actions described by Bleuler, or ‘loss of self-evidence’ described by Blankenburg. These authors regarded self-disorders as the core deficit in schizophrenia. Multisensory strategies intended to repair perceptual incoherence, may lead to impaired source monitoring and positive symptoms. Here we discussed a sensory model in which positive symptoms may result from coping strategies in order to soothe alienating self-experiences. The pattern of multisensory integration or co-weighting of body-centred and environment-oriented input during body-perception in schizophrenia warrants further investigation. More insight in multisensory mechanisms may increase our understanding of psychopathogenesis of schizophrenia. A better understanding of perceptual incoherence and self-disorders as disturbing, incoherent perceptions that cause suffering and decline of functioning, may improve recognition of high-risk individuals. Differentiation of ultra-high-risk groups may improve recognition of early stages of schizophrenia. The perceptual incoherence hypothesis may offer to patients a plausible explanation for self-disorders. Such explanations might prevent patients’ search for existential clarifications or formation of delusions. Some patients may realise that their coping strategies aggravate perceptual incoherence. Complementary sensory therapies may diminish perceptual incoherence and thereby alleviate incoherent self-experiences.

Author contributions

All authors contributed to, reviewed and edited the manuscript. JS and HH provided input. LP created the initial concept. LP, SG and HS participated in discussions and wrote the manuscript, supervised by LH.

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