

Social Sciences

Proprioception and Tactile Perception in Schizophrenia

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The aim of this review is to investigate the relationship between proprioceptive and tactile perceptual aberrations and the psychotic symptoms of schizophrenia, a correlation which has already been established by several studies (Lenzenweger, 2006; Postmes et al., 2014; Chang and Lenzenweger, 2005; Michael and Park, 2016; Germine et al., 2013; Kent et al., 2010). However, the direction of causality within the correlation is still unknown. Because several studies indicate an abnormal and uneven weighting of the senses in schizophrenic multisensory integration, it is possible that the psychotic symptoms of schizophrenia may be due to multisensory integration abnormalities involving proprioceptive and tactile perception. Several theories have also been proposed that schizophrenia itself is the cause of these proprioceptive and tactile perception anomalies. There could also be neuroanatomical factors that underlie both the schizophrenia psychotic symptoms and proprioceptive and tactile perception aberrations. Because of limitations in the current research, a definite causal direction is still unable to be determined. Several practices to improve the methods of analysis in this field of study include incorporating measures of schizotypy with less subjectivity and using longitudinal neurodevelopmental studies to pinpoint developmental aberrations in proprioception, tactile perception, and the correlated psychotic symptoms of schizophrenia. These methods may lead to better pre-emptive target interventions and could establish the directionality of causation between proprioception and tactile perception anomalies and positive schizophrenia symptoms.

INTRODUCTION

Schizophrenia is a chronic neuropsychiatric condition that affects nearly one percent of the world's population. It presents with a vast array of both positive symptoms such as hallucinations and delusions, and negative symptoms such as anhedonia and avolition. However, the core feature of schizophrenia has been suggested to be an anomalous sense of the bodily self that is manifested as a loss of body ownership, agency, and disembodiment. While it has been difficult to empirically study bodily self-disturbances, it has long been known that impairments of proprioception and tactile perception are prevalent in schizophrenia-spectrum conditions. Proprioception is the sense of the body's position in space while tactile perception is the somatosensation of touch. This paper will focus on the proprioceptive and tactile perception aberrations found in schizophrenia as a potential source for the characteristic loss of sense of self and distorted boundaries of the body.

In order to do this, a brief overview of tactile perception and proprioception will be introduced, followed by a review of tactile and perceptual

anomalies in schizophrenia. Then, potential neurocognitive mechanisms underlying these impairments will be examined. Finally, some limitations and possible future directions will be discussed.

GENERAL OVERVIEW OF PROPRIOCEPTION AND TACTILE PERCEPTION

Proprioception is the sense that allows the perception of the location, movement, and action of different parts of the body. It enables the judgment of limb movements and positions and combines with other sensory input to allow the differentiation of external objects from the internal body, contributing significantly to body image. Proprioception has both conscious and unconscious pathways. The conscious proprioceptive pathways follow muscle spindles to the dorsal column and spinocervical tract and finally, the somatosensory cortex. In comparison, the unconscious proprioceptive pathway involves muscle spindles and the spinocerebellar tract. The sensory receptors of both of these pathways are mechanoreceptors and proprioceptors, primarily

muscle spindles, tendon afferents, cutaneous receptors, and joint receptors in the skin, muscles, and joints. Populations of afferent neurons send signals from these proprioceptive receptors to be checked against a central body map and determine the location of limbs in space.

Tactile perception is one of the five somatosensory senses. It encompasses the capability to perceive pressure, stretch, vibration, temperature, and pain. Because tactile perception is a type of exteroception, it allows the differentiation of the boundaries of the body from the external environment. The pathway involved in tactile perception consists of afferent signals from the various touch receptors to the dorsal root ganglion to the dorsal columns to the ventral posterior nucleus of the thalamus, and then finally, the somatosensory cortex. Due to the integration of both the conscious proprioceptive and tactile perception pathways in the somatosensory cortex, deficits in the integration of one pathway would likely mean deficits in the second one.

PROPRIOCEPTIVE AND TACTILE PERCEPTION DEFICITS IN SCHIZOPHRENIA

Past research indicates that proprioceptive perception and tactile perception are impaired in schizophrenia (Lenzenweger, 2006; Postmes et. al, 2014; Chang and Lenzenweger, 2005; Michael and Park, 2016; Germine et. al, 2013; Kent et. al, 2010). Tactile perception allows for the body's ability to differentiate itself from external space because somatosensory sensations are a highly relevant factor in the discrimination of where the body begins and ends. In other words, touch marks the boundary between the "self" and the outside world. Because tactile perception is so important for the establishing of a bodily boundary, this sense is crucial to consider in a condition that presents such anomalous experiences with sense of self and body boundaries. In fact, reduced exteroceptive abilities with tactile perception can even increase one's risk of psychotic experiences such as hallucinations and delusions (Postmes et. al, 2014).

An example of the reduced exteroceptive

abilities of patients with schizophrenia is the two-point discrimination task. Individuals with schizophrenia and those at risk for schizophrenia are known to have reduced tactile accuracy on the two-point tactile discrimination task, which requires the participant to determine whether the tactile stimulus on the skin consists of one or two sharp points (Chang and Lenzenweger, 2005; Michael and Park, 2016). Tactile discrimination deficits are also associated with psychometric schizotypy indicators in healthy individuals, including high scores on the Perceptual Aberration Scale (Chapman et. al, 1978) or the Schizotypal Personality Questionnaire (Raine, 1992), which assess psychosis-proneness or psychosis-risk associated with tactile deficits (see Lenzenweger, 2000; Michael and Park, 2016).

In addition to basic tactile deficits, there are also higher-order impairments that involve the sense of touch. Schizotypal individuals show deficits in graphesthesia, which is the ability to transform tactile sensation into a visuospatial format. For example, a letter is traced on the back of an individual with a pen or a finger and the participant is asked to guess what letter it was. Control participants are able to perceive and transform the spatial layout of the tactile stimulation into visual imagery and recognize the letter while schizotypal individuals are impaired on this task (Chang and Lenzenweger 2005). Thus, not only are they impaired in simple perception of tactile stimuli, they are also impaired in multisensory integration of the input.

With respect to proprioception, there have been a wide range of empirical studies that provide evidence for abnormal proprioception in the schizophrenia-spectrum. One example is the case of postural sway. Postural sway refers to the unconscious, small movements around the body's center of gravity that help maintain balance. This fine motor behavior requires cerebellar integration of visual, proprioceptive, and vestibular information to correctly orient the body in space and maintain a standing position. Since the cerebellum, which is involved in postural control, is an integral part of several circuits that are abnormal in patients with schizophrenia, studying postural sway is

useful for understanding the integration of visual, proprioceptive, and vestibular information in schizophrenia. In one 2012 study, postural sway was investigated in several different conditions, including with the eyes closed or open, and feet close together or shoulder-width apart. When the sway area, as measured by an ellipse surrounding the deviations from the center of the participant's center of gravity, was compared between the control group and the schizophrenia group, the schizophrenia group exhibited greater sway area overall. The schizotypal group also had a pattern of having a significantly larger sway area when the eyes are closed than when the eyes were open, but this pattern wasn't present in controls. This showed that the schizophrenia group was more affected by the loss of visual input than the control group (Kent et. al, 2012). Since proprioception and tactile perception is generally abnormal in patients with schizophrenia, their brains likely overcompensate with their other inputs, especially the visual input. Thus, multisensory integration abnormalities may potentially lead to hallucinations and other psychotic experiences.

Schizophrenia-spectrum individuals also show an increased tendency to experience proprioceptive illusions, such as the Pinocchio illusion (Michael and Park 2016). In this experiment, participants were blindfolded and asked to place their hand on their nose. Then, the muscles in their biceps were stimulated through vibration, creating the illusion of their arm extending. Even though the hand is still in contact with the nose, the proprioceptive muscle spindles of the biceps are sending signals to the somatosensory cortex that the arm is extending, so the participant feels as if their nose has elongated. This is an example of how the brain may resolve the conflict between proprioceptive and tactile inputs by creating an illusionary experience that violates the perception of the stability of the body boundary. Those with a stable sense of the body boundary would be less susceptible to Pinocchio Illusion because they are certain that the boundary of their bodies (e.g. the nose in this case) is invariant. However, individuals with schizophrenia are uncertain of their self-boundaries, and thus more

susceptible to the proprioceptive illusion.

In the case of the Pinocchio illusion (PI), the participants felt a body part changing in size due to the abnormal weighting of the proprioceptive input against other sensory inputs. In the case of another proprioceptive, multisensory illusion known as the rubber hand illusion (Botvinick and Cohen, 1998), susceptible participants experience a change in their sense of body ownership, due to conflicting multisensory integration between proprioceptive and visual inputs. In a striking example of delusional experiences caused by the conflict between the proprioceptive and visual senses, the rubber hand illusion (RHI) creates the illusion of ownership of a rubber hand after pairing visual stimuli with proprioceptive stimuli. In this intriguing paradigm, the participant's own hand is hidden from view and a rubber hand is placed within their view. The fake rubber hand and the real hand are then brushed at the same time. After a while, participants report feeling the brush stroke on the rubber hand as if the fake hand is their own. Essentially, their body boundary has expanded to include the visible rubber hand while disowning their own unseen hand. Patients with schizophrenia, and those at risk of developing it, are very susceptible to this illusion (Peled et al., 2000, 2003; Thakkar et al., 2011; Germine et al., 2013). The increased susceptibility of patients with schizophrenia to proprioceptive illusions like the RHI is a clear example of how abnormal multisensory integration between proprioception and vision can induce an illusion (Botvinick and Cohen, 1998).

Size-weight illusion (SWI) is also altered in schizophrenia (Williams et al., 2010), but in an interesting direction. Participants are asked to judge the weight difference between two differently sized objects with the same mass. Control participants perceive the smaller object as heavier despite both objects having the same mass; this is called the SWI. The SWI arises from a violation of the common expectation that the large object is heavier. In the real world, this is generally true. However, in this experiment, there is a mismatch between the expectation from the size information and the

feeling of the weight in the hand (proprioception). Patients with schizophrenia tend to perceive the two objects to be the same weight regardless of their visual size, indicating that they are not susceptible to SWI. Hence, they actually perform 'better' than controls on this task. One might think this finding is discrepant with the results of the PI or the RHI because in the SWI, schizophrenia patients are able to override the visual input in favor of the proprioceptive signals. However, there are major differences in these paradigms. SWI does not involve bodily-self boundary nor does it involve body ownership or agency. It is a task that requires the participant to make a judgment about an external object. Therefore, in this task, the important message is the fact that the patients do not seem to use or possess ecologically-valid top down knowledge (i.e. larger objects are usually heavier) to make judgments about the world. Thus, in this particular task, they show a 'superior' performance but in the real world, this inability to incorporate a physical knowledge of the world would be maladaptive.

These studies indicate not only an abnormal uneven weighting of the senses in schizophrenic multisensory integration but also an abnormal integration of expectations about the world into ongoing experiences.

PSYCHOLOGICAL AND NEURAL MECHANISMS UNDERLYING ALTERED PROPRIOCEPTIVE AND TACTILE PERCEPTION IN SCHIZOPHRENIA

One of the prevailing theories for the relation between proprioceptive anomalies and schizotypy posits that the "perceptual incoherence" between conflicting senses contributes to certain psychotic hallucinations. In this theory, the sensory processing impairments that are characteristic of schizophrenia affect multisensory integration. The resultant perceptual incoherence can lead to self-experiences like depersonalization and lowered coherence between thoughts, words, and actions (Sass and Parnas 2003). The attempt to restore perceptual coherence may induce hallucinations and delusions (Postmes et. al, 2014).

Perception aberrations, according to several somatosensory integration theories, could lead to impaired remapping of environmental stimuli in bodily space (Ferri et. al, 2016). High schizotypes have worse touch remapping than low and moderate schizotypes, indicating overall remapping of environmental stimuli in bodily space has a negative association with the severity of schizophrenia symptoms. Since this remapping is vital for the differentiation of internal and external stimuli and contributed to by both proprioceptive and tactile information (Ferri et. al, 2016), this theory supports that proprioceptive and tactile perception anomalies can lead to the psychotic symptoms characteristic of schizophrenia.

Another relevant theory is the cognitive dysmetria theory. It posits that schizophrenia is caused in part by an underlying dysfunction in the neural circuits that provides connectivity and feedback between cortical regions in the cerebellum, namely the cortico-cerebellar-thalamic-cortical circuit, or CCTCC. It is important to note here that the CCTCC circuit has several nodes that are integral parts of both the conscious and unconscious proprioceptive pathways as well as the tactile perception pathway. A malfunctioning version of this circuit produces a significant cognitive deficit, which is called "cognitive dysmetria" (Andreasen 1998). When using anatomic MR, structural equation modeling, and diffusor tensor imaging, the CCTCC circuit was found to be impaired in patients with schizophrenia in comparison to healthy volunteers (Andreasen 1998, Kent et. al, 2012). Evidence for this theory was supplemented later by a similar fMRI study which resulted in a similar conclusion (Honet et. al, 2005).

The theory of somatosensory integration issues and conflicting proprioceptive and other stimuli leading to psychotic experiences can also be explored using the CCTCC. The CCTCC involves reciprocal connections between the cerebellum and the frontal cortex with the thalamus as a mediary. These connections allow for the coordination and integration of motor and thus proprioceptive movement in an efficient manner. In schizophrenia, the nodes of this proprioceptive

system are impaired. The result of this is called “cognitive dysmetria” and it is essentially a disruption of perception and behavior. Because the CCTCC is a proprioceptive pathway that is aberrant in schizotypal individuals, the cognitive dysmetria theory points to proprioceptive and tactile aberrations leading to psychotic symptoms like hallucinations and delusions.

An important theory to reference here is the corollary discharge theory. In this theory, as action potentials are sent to the muscles to initiate movement, corresponding signals are also sent to the somatosensory cortex. These corollary discharges are used to differentiate between self-generated stimuli and externally generated stimuli (Craipse and Sommer 2008). The proprioceptive and tactile perception pathways described earlier are likely supplemented through corollary discharges. Corollary discharge mechanisms and pathways allow for sophisticated sensorimotor and neurocognitive operations like perceptual stabilization and sensorimotor learning. At a psychological level, they create a sense of self in the proprioceptive experience that is not prevalent in schizophrenia. As a result, early-onset corollary discharge impairment will lend itself to a distortion in perception, leading to potential psychotic experiences. This provides a specific pathophysiological link between proprioceptive impairment and long-term risk of psychosis (Kent et. al, 2012).

DIRECTIONALITY OF EFFECTS: DOES SCHIZOPHRENIA CAUSE TACTILE AND PROPRIOCEPTIVE DEFICITS?

The directionality of causation between tactile perception and proprioception aberrations and psychotic symptoms is still unknown. If it is assumed that proprioceptive and tactile perceptual anomalies lead to the psychotic experiences that define the condition of schizophrenia, then the gene-environmental interactions that define many psychiatric disorders are discounted. For example, the effect of socially reclusive behavior from a young age, which young patients with schizophrenia are at risk for, on the proper

development of proprioceptive and tactile senses would be disregarded (Ballon et. al, 2011). On the other hand, if it is assumed that the psychological and neural mechanisms associated with schizophrenia lead to proprioceptive and tactile perception aberrations, then studies that establish poor proprioceptive abilities in high-risk individuals, schizotypal individuals, and prodromal individuals that don't have the condition of schizophrenia would be discounted. There is also a third possibility to consider, which is that there could be factors underlying both schizophrenia and proprioceptive and tactile perception anomalies that explain both. Of course, there is likely a cyclical and compounding positive feedback loop involved with all three of these possibilities, but it is still important to investigate the original point of causation of the three in order to develop better-targeted intervention practices to treat patients with schizophrenia earlier and more effectively in the future.

There are developmental factors to consider. The nervous system constantly adapts in response to environmental demands and changes. If the environmental inputs are disrupted, it could lead to abnormal neural development. Proprioception, for example, in order to properly develop, needs dynamic multisensory interactions with the environment from the early stages of development in order to eventually develop a proper sense of body boundaries (Piaget and Inhelder, 1967). Especially as newborns, where the body hasn't begun to rely on the weaker visual stimuli as much as tactile and proprioceptive stimuli, it is absolutely vital that they receive proper tactile stimuli to learn more about the new environment. Essentially, sense of self and bodily boundaries are shaped by interactions with the world.

In general, several of the negative symptoms of schizophrenia include social withdrawal, anhedonia, and avolition. Many of these negative symptoms tend to cause schizophrenia patients to self-isolate and thus experience decreased social interactions. The decrease in social interaction likely contributes to the proprioceptive and tactile perception aberrations perceived in patients with

schizophrenia. Social isolation and withdrawal can lead to an increased risk of developing psychotic symptoms (Allé and Bernstein 2021), and part of this might be due to the reduced tactile stimuli that occur when one is alone. In fact, in cases of extreme social isolation involving sensory deprivation, such as in solitary confinement, even previously healthy patients tend to develop psychotic hallucinations of the visual, proprioceptive, and tactile variety (Solon et. Al, 1961). This points the direction of causality in the direction of schizophrenia causing proprioceptive and tactile perception anomalies. However, as stated before, there are several other factors that may contribute.

NEUROANATOMICAL FACTORS UNDERLYING BOTH SCHIZOPHRENIA AND PROPRIOCEPTIVE AND TACTILE ANOMALIES

Investigating the neuroanatomical factors that underlie both schizophrenia and proprioceptive and exteroceptive anomalies is vital to properly understand the course of the disorder and how best to create earlier treatments for it.

There are several neuroanatomical factors underlying both proper proprioceptive function and schizophrenia symptoms. Studies indicate structural deficits like reduced gray matter volume may be progressive in the onset and early-onset portions of the disorder (Karlsgodt et. al, 2010). Gray matter is also known to be a part of the vital sensory integration that is disrupted in the proprioceptive anomalies accompanying schizophrenia (Yoshimura et. al, 2017). Numerous brain imaging research studies have revealed reduced gray matter volume in patients with schizophrenia involving multiple brain regions, such as the frontal cortex, the temporal lobe, and the insula (Honea et. al, 2005). Because gray matter, which has an important role in sensory integration, is reduced in volume in patients with schizophrenia, it can be hypothesized that gray matter abnormalities in the brain may lead to certain psychotic experiences in schizophrenia as well as proprioceptive anomalies.

In addition to studies regarding gray matter

abnormalities in the brain, several studies of patients at risk for schizophrenia indicated early changes in the parietal lobe (Yildiz et. al, 2011), the inferior portion of which is involved in somatosensory integration. There were also structural abnormalities in the insula (Honea et. al, 2005), which integrates sensory signals from the body with emotional and motivational context with the dorsomedial frontal cortex to initiate and sustain bodily movement.

DISCUSSION

Due to several limitations in the current research papers on schizophrenia and proprioception and tactile perception, it is difficult to discern the exact nature of the relationship between proprioception and tactile perception anomalies. In the future, it is imperative to carry out longitudinal studies measuring the neurodevelopmental effect of lack of proper tactile stimuli as a potential cause for schizophrenia. If longitudinal studies measuring the development of positive schizophrenia symptoms are done on at-risk individuals with and without exposure to adequate tactile stimuli in their neurodevelopment, then it is likely additional information regarding the direction of causality between the factors would come to light. The current research is also limited to small sample sizes and conflicting replication study results, which are a reflection of issues with both internal and external validity. Because of this, it is essential to carry out studies with a larger sample size and replicate these studies in a consistent manner. It is also important to improve on the subjectivity of the scales that allow the classification of individuals as schizotypes such as the Perceptual Aberration Scale and Schizotypal Personality Questionnaire. Because these scales are usually filled out by the subject, the subject ultimately delineates what is considered abnormal to them. Someone else may have the same experience, but consider it normal and have a different score. This is why objectivity in determining schizotypy would be beneficial in the determination of causality between tactile and proprioceptive perceptual aberrations and the positive symptoms of schizophrenia. Since there

has been an established link between objective measures such as two-point discrimination and schizotypy, perhaps these measures should be used instead in the future. Designing studies that utilize more proprioceptive and tactile perception tasks and illusions like the rubber hand illusion, the graphesthesia task, and of course, the two-point discrimination task is essential to uncovering more in this field of study.

In conclusion, this literature review analyzed various studies on proprioception and tactile perception aberrations in schizophrenia in order to investigate the directionality of the causation in these two factors. However, it is still unclear whether proprioceptive and tactile aberrations cause schizophrenia, if schizophrenia leads to proprioceptive and tactile anomalies, or if there are neuroanatomical factors underlying both. While there is sufficient evidence to support a correlation between the two factors, there haven't been enough objective experimental longitudinal studies to establish the causal relationship.

CONFLICTS OF INTEREST

The author has not disclosed any conflicts of interest.

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Motivated by her experiences as a dementia care practitioner, Shadhvika developed a particular passion for the destigmatization of mental health through a scientific lens. From her interactions with her patients in both the memory care center and the Neurology unit of Ascension St. Thomas, she believes that some of the stigma associated with mental illnesses results from a lack of knowledge of the diseases themselves. To this extent, she loves raising awareness of mental health, and especially its intersection with culture. On campus, she does this by helping organize speaker events and volunteering opportunities as Advocacy Chair for MoveMENTAL, an organization dedicated to the intersection between mental health and cultural identity. Off campus, she works as a mental health group counselor in Innerworld, a virtual reality platform that provides accessible mental health help whenever needed. For the past couple years, she has

also been conducting research with the Johnson Lab on circadian rhythms, which has extensive implications in the study of depression and many sleep disorders. This particular paper was inspired by a class on Schizophrenia taught by Dr. Sohee Park. Intrigued by the various neuroanatomical models and theories covered in class, Shadhvika wrote this paper tying together her greatest interests in the class: aberrations in neuroanatomical pathways and delusions and hallucinations experienced by individuals with schizophrenia. It is her hope that more knowledge about the causation of the positive symptoms of schizophrenia will lessen the stigma of this condition in society.