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Schizophrenia and the inferior parietal lobule

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Abstract

Objective: Studies of the neuroanatomical localization of schizophrenia have not given sufficient attention to the inferior parietal lobule (IPL).
Methods: A search of the medical literature was carried out for links between schizophrenia and the IPL.
Results: Structural differences in the IPL in schizophrenia were reported by 10 recent neuroimaging studies, although the studies did not all agree with each other. Functional differences in the IPL in schizophrenia have been prominently reported in four areas: sensory integration, body image, concept of self, and executive function.
Conclusion: The IPL appears to be an important, but relatively neglected, component of the frontal–limbic–temporal–parietal neural network involved in the schizophrenia disease process. To encourage histopathological research of this area, the Stanley Medical Research Institute is making available a new collection of sucrose-fixed IPL tissue from 25 individuals with schizophrenia and 25 matched controls. Additional imaging and functional studies are needed to better define the network and role of the IPL.
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Keywords: Schizophrenia; Inferior parietal; Angular gyrus; Supramarginal gyrus; Anosognosia

Contents

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1. Introduction and methods

For more than a century, researchers have speculated regarding the localization of schizophrenia in the brain. By the 1980s, a reasonable consensus had emerged that the disease involves reciprocally connected prefrontal, temporal, and inferior parietal neocortical areas and the closely linked hippocampus, amygdala, and septum in the limbic system. According to Zec and Weinberger's 1986 summary, these structures form "an integrated network of neural systems… it is conceivable that damage at a single strategic location could cause widespread dysfunction… almost any location in this network could be considered a site of the lesion in schizophrenia" (Zec and Weinberger, 1986).

In the two decades since this review, evidence has accumulated suggesting that schizophrenia is not a disorder of a single brain area but is indeed a disorder of brain networks, such as described by Mesulam (1990, 1998). As summarized in a review by Davis et al. (2003): "Numerous lines of inquiry implicate connectivity as a central abnormality in schizophrenia." The superior longitudinal fasciculus, connecting the frontal and parietal areas, is among the tracts exhibiting abnormalities (Buchsbaum et al., 2007). Other recent studies have reported "altered white matter integrity in the tracts connecting the frontal cortex with the temporal and parietal cortices" (Shergill et al., 2007) and evidence of disruption of "the entire fronto-parietal circuitry" (Karlsgodt et al., 2007).

Although the parietal cortex in general, and the inferior parietal lobule (IPL) in particular, is generally believed to be an important part of the schizophrenia network disorder, it has received relatively little attention compared to the prefrontal cortex, hippocampus, or cingulate. As noted by Maruff et al. (2005), "the parietal lobe receives little attention in current neuropathological models of schizophrenia and there has been little systematic investigation of this area." A PubMed search of publications from 1987 through 2006, using as keywords "schizophrenia" and "frontal" or "prefrontal," identified 3573 articles, but another search, using as keywords "schizophrenia" and "parietal" or "inferior parietal," found only 530 articles. A major reason for this paucity of parietal studies is that it is a difficult region to study.

The inferior parietal lobule (IPL) consists of the supramarginal gyrus (Brodmann area 40) and adjacent angular gyrus (BA 39). Although the Brodmann bipartite division is still widely used, recent histological studies of the inferior parietal area describe it as being divided into 7 cytoarchitectonic areas, 5 in BA 40 and 2 in BA 39 (Zilles et al., 2003; Caspers et al., 2006). Thus, studying random sections from either Brodmann areas, unless carefully matched to controls, may yield spurious findings.

A second reason why it is a difficult area to study is that the IPL is thought to be one of the last areas of the human brain to mature. Flechsig, in his classic myelination studies, identified the supramarginal and angular gyri as being among the last areas to myelinate (Flechsig, 1920). Geschwind (1965) said that the IPL was "one of the last cortical areas in which dendrites appear" and added that "it matures cytoarchitechtonically very late, often in late childhood." The late maturation of the IPL is generally assumed to correlate with its relatively late development in the evolution of the human brain. One consequence of the late development of the IPL is that it is anatomically highly variable. Bailey and von Bonin (1951) noted that "the cortex of the inferior parietal lobule has caused difficulties to all observers" and added that "the gyral pattern… is so varied as to be useless." Ingalls (1914) claimed that "there is probably no region in which it is more difficult to find fixed landmarks for a comparative study" and suggested that the region has evolutionarily "not yet reached its full development." This anatomical variability causes major problems in establishing landmarks for neuroimaging and neuropathological studies. Moreover, histologically the supramarginal and angular gyri merge with the adjacent temporal lobe; "the posterior portion of the middle and inferior temporal convolutions resemble that of the inferior parietal region so closely as to be impossible of certain recognition" (Bailey and von Bonin, 1951).

Another consequence of the late evolutionary development of the IPL is that some researchers have claimed that analogous areas have not been identified in monkeys, and "even in higher apes these areas are present only in rudimentary form" (Geschwind, 1965). Much of what is known about human brain function is derived from studies of monkeys, so consequently much less is known about the function of the IPL compared to other brain areas. It is thought that the most important connections of the parietal lobe are to the prefrontal cortex (Petrides and Pandya, 1984; Chafee and Goldman-Rakic, 2000), cingulate (Mesulam and Geschwind, 1978), and temporal cortex (Seltzer and Pandya, 1984), but these and other connections have not been well studied in humans.

Much of what has been described in IPL function in humans has been derived from studies of strokes and epilepsy of this region. However, if the IPL is centrally involved in schizophrenia, it is questionable whether an abrupt, hypoxic episode late in life or an epileptic electrical discharge would be expected to impair IPL function in a way similar to the impairment caused by a less abrupt lesion early in life.

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Table 1
Imaging studies of inferior parietal lobule in schizophrenia

Authors and year	Number of subjects with schizophrenia	Significant results
Goldstein et al. (1999)	29	↓ R and L supramarginal gyrus
Niznikiewicz et al. (2000)	15 (males only)	↑ R angular gyrus and reversed IPL asymmetry
Frederikse et al. (2000)	15	↓ L IPL volume in males and reversed IPL asymmetry in males
Wilke et al. (2001)	48	↓ IPL volume correlated with severity of symptoms
Hulshoff et al. (2001)	159	↓ R supramarginal gyrus
Kubicki et al. (2002)	16 (first episode)	↓ R IPL
Shapleske et al. (2002)	72	↑ R supramarginal gyrus
Buchanan et al. (2004)	44	↑ R supramarginal gyrus and reversed IPL asymmetry
Nierenberg et al. (2005)	14 (first episode)	↓ L angular gyrus
Zhou et al. (2007)	53	↓ R and L supramarginal gyrus ↓ R and L angular gyrus and reversed supramarginal asymmetry

Finally, studying the IPL is made difficult by the fact that it is among the most highly lateralized areas of the brain and immediately contiguous with the planum temporale, which in the dominant lobe includes Wernicke's language area. The relative importance of the two hemispheres in schizophrenia remains controversial (Nasrallah, 1986), although there is some evidence for decreased cerebral lateralization in this disease (Dollfus et al., 2006). In addition to being lateralized, the IPL shows sexual dimorphism, with the left IPL being larger in males than in females, which may be associated with some of the cognitive differences between the sexes (Frederikse et al., 1999). The practical importance of this research on the IPL is that controls must always be matched to study subjects by both brain hemisphere and sex.

2. Results

2.1. Studies of IPL structure in schizophrenia

Among the first English-language reports of IPL structural abnormalities in individuals with schizophrenia was that by von Angyal (1934), who noted that "based on the latest histological studies, it appears to be without doubt that the inferior parietal lobule, i.e., the supramarginal gyrus, angular gyrus, and basal parietal area, belong to the cortical regions most seriously damaged by the schizophrenic disease process." Von Angyal based his opinion on detailed neuropathological studies carried out by a Hungarian neuropathologist, Dezso Miskolczy. After studying the brains of 13 individuals with schizophrenia, Miskolczy concluded that neuronal cell losses and mild glial proliferation were most pronounced in the prefrontal, superior temporal, temporal pole, and IPL. These areas, he said, were the "human parts of the brain… and therefore the superior psychological functions suffer disturbances" (Miskolczy, 1933).

In recent years, virtually all structural studies of the IPL have been done using neuroimaging techniques. Several studies have measured the entire parietal lobe (Cleghorn et al., 1989; Berman et al., 1989; Egan et al., 1994; Andreasen et al., 1994; Nopoulos et al., 1995; Yoon et al., 2006) or combined the IPL with other brain areas (Jernigan et al., 1991; Harvey et al., 1993; Zipursky et al., 1994; Bilder et al., 1994; Schlaepfer et al., 1994; Marsh et al., 1999; Lim et al., 1999; Bilder et al., 1999; Dubb et al., 2005; Whitford et al., 2005). Since 1999, however, 10 studies using various imaging techniques have studied the IPL in individuals with schizophrenia and controls; 6 reported a significant decrease in volume (one of them in males but not females), 3 reported a significant increase, and 1 reported a correlation between decreased volume and severity of symptoms (Table 1). Four studies also examined the asymmetry of the IPL; in normal individuals, the left side is larger, but in all 4 studies of individuals with schizophrenia the asymmetry was reversed. One study also included individuals with affective psychosis and reported no significant IPL changes for this group. The lack of consistency in the volumetric findings is due in part to the use of different imaging techniques, the use of different anatomical landmarks, and differences in the selection and number of patients and controls. Similar inconsistencies have been found in imaging studies of frontal and temporal structures (Shenton et al., 2001).

2.2. Studies of IPL function in schizophrenia

Macdonald Critchley, in his book *The Parietal Lobes* (1953), claimed that "within the brain, no territory surpasses the parietal lobe in the rich variegation of clinical phenomena which follows disease states." This is probably most true for the IPL. In reviewing studies of brain function in schizophrenia, there appear to be at least four major IPL functions that are impaired in

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individuals with schizophrenia. These are sensory integration, body image, concept of self, and executive functions.

2.2.1. Sensory integration

The IPL is known to be an essential part of the heteromodal association area, defined by Pearlson et al. (1996) as also including the dorsolateral prefrontal cortex (BA 9 and 46); Broca's area (parts of BA 6, 44, 45, and 47); and part of the superior temporal gyrus (BA 22), including Wernicke's area. These constitute "an interconnected family of higher-order neural circuits" that has "rich and extensive interconnections with specific areas within the limbic system, especially to paralimbic regions such as cingulate cortex, parahippocampal gyrus, and caudal orbitofrontal cortex" (Pearlson et al., 1996). An important function of heteromodal association areas is to integrate information coming from the visual, auditory, and tactile sensory modalities; evaluate the information; and plan a response. As an example of this function, one observer, in discussing the evolutionary origins of the IPL, said that the IPL is where "all the 'facts' about snakes can be stored and retrieved, whether one sees, hears, or touches one" (Bear, 1983). The supramarginal and angular gyri are especially well situated to integrate incoming sensory data and have been called by Geschwind "an association area of association areas" (Geschwind, 1965). It was this sensory integration function that C.S. Sherrington was referring to when he likened the brain to "an enchanted loom… [weaving] a dissolving pattern, always a meaningful pattern though never an abiding one; a shifting harmony of sub-patterns" (Sherrington, 1940).

Disruption of sensory integration is one of the earliest and most common symptoms of schizophrenia. According to one study, "perceptual dysfunction is the most invariant feature of the early stage of schizophrenia" and is found in almost two-thirds of patients (Cutting and Dunne, 1989). Such perceptual dysfunctions may include noises sounding louder, colors looking brighter, or touch feeling sharper. As described by one patient:

> "Everything looked vibrant, especially red; people took on a devilish look with black outlines and white shining eyes; all sorts of objects-chairs, buildings, obstacles-took on a life of their own; they seemed to make threatening gestures, to have an animistic outlook." (Cutting and Dunne, 1989)

Under normal conditions, the IPL sorts and integrates the multiple sensory data as it arrives. When the IPL is not functioning, however, the individual may be flooded with stimuli:

> "Everything seems to grip my attention although I am not particularly interested in anything. I am speaking to you just now, but I can hear noises going on next door and in the corridor. I find it difficult to shut these out, and it makes it more difficult for me to concentrate on what I am saying to you." (McGhie and Chapman, 1961)

It thus becomes very difficult for the person to integrate sensory data into a coherent pattern:

> "I have to put things together in my head. If I look at my watch I see the watchstrap, watch, face, hands and so on, then I have got to put them together to get it into one piece." (Chapman, 1966)

Given such difficulty in integrating sensory data, many individuals with schizophrenia find it difficult to respond appropriately. This may lead to thought blocking:

> "When people are talking I have to think what the words mean. You see, there is an interval instead of a spontaneous response. I have to think about it and it takes time. I have to pay all my attention to people when they are speaking or I get all mixed up and don't understand them." (McGhie and Chapman, 1961)

Alternatively, it may produce a loosening of associations:

> "I feel that everything is sort of related to everybody and that some people are far more susceptible to this theory of relativity than others because of either having previous ancestors connected in some way or other with places or things, or because of believing, or by leaving a trail behind when you walk through a room you know. Some people might leave a different trail and all sorts of things go like that." (Mayer-Gross et al., 1969)

In fact, most aspects of what is characterized as a thought disorder are probably explainable as defects in the sensory integration system of the IPL and other parts of the heteromodal association cortex.

Sensory data may be blunted as well as enhanced. The blunting has been described "as if a heavy curtain were drawn over his mind; it resembled a thick deadening cloud that prevented the free use of his senses" (Freedman, 1974). One's own voice may sound muted or faraway, and vision may be wavy or blurred.

A dramatic example of the blunting of sensory data is pain. Studies have shown that the IPL is "uniquely involved in the conscious subjective experience of pain"

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(Apkarian et al., 1999). Geschwind (1965) noted that "the cortical end-stage of the pain pathway lies in the supramarginal gyrus," and Critchley added that when the parietal lobe is damaged "the patient, though not insensitive to pain, displays an altered and unusual attitude toward pain-producing stimuli… a morbid indifference toward painful stimuli" (Critchley, 1953). A relative insensitivity to pain in some individuals with schizophrenia was noted by Kraepelin and Bleuler and has led to many untreated medical and surgical emergencies over the years (Bickerstaff et al., 1988; Dworkin, 1994). One study of pain insensitivity reported that it occurred in 16% of individuals with schizophrenia (Tyler, 1995). Another study demonstrated that the person's pain threshold was not altered but rather their attitude toward pain; the authors concluded that "the term of 'indifference' to pain may be more appropriate than 'insensibility' to pain" (Guieu et al., 1994).

Additional examples of impaired sensory integration are neurological soft signs such as stereognosis (identifying objects in hand with eyes closed); graphesthesia (identifying numbers written on palm of hand with eyes closed); and double-simultaneous stimulation (perceiving two simultaneous touches on hands and face with eyes closed). Studies have shown that at least half of individuals with chronic schizophrenia have such abnormalities (Torrey, 1980; Manschreck and Ames, 1984) and that they occur in individuals who have never been treated with antipsychotic medication (Keshavan et al., 2003). Such neurological soft signs have been linked to dysfunction of the parietal lobes and in some cases specifically to the supramarginal gyrus (Critchley, 1953; Lishman, 1978).

2.2.2. Body image

Body image refers to the person's awareness of bodily self. Critchley noted the important role of the parietal lobes in forming "corporal awareness" (Critchley, 1953); more recently, others have confirmed the role the posterior parietal plays in our corporeal awareness (Berlucchi and Aglioti, 1997).

Disturbances in body image have been extensively described in individuals with schizophrenia. Angyal (1936) claimed that 15% of patients have some disturbance of body image and, based on his own research and that of others, suggested that "the cortical tissue along the interparietal sulcus, the gyrus angularis and the posterior part of the gyrus supramarginalis seem to be the most important parts for the postural recognition and related functions." Cutting (1989) reported disorders of body image in 45% of consecutive schizophrenia admissions; the most common manifestations were alterations in structure, shape, or weight, e.g., "head stretched from body," "penis turning inside out," and "cat semen in blood."

An especially common disturbance of body image in individuals with schizophrenia is right–left disorientation, in which the individual confuses the two sides. A test of this is commonly included on the neurological examination, with the examiner crossing his/her arms and asking the patient to point to the examiner's left hand. Right–left disorientation has been linked to dysfunction of the angular gyrus (Bychowski, 1943).

The most serious disturbance of body image associated with parietal lobe damage is neglect of one side of the body and denial that anything is wrong. This is seen following strokes to the nondominant parietal lobe, especially when the IPL is involved (Vallar and Perani, 1986). The picture is often bizarre, with a hemiplegic patient lying in bed claiming that nothing is wrong. Such lack of awareness is called anosognosia and has been linked to parietal lobe function, especially the IPL (Critchley, 1953; Gerstmann, 1942). As discussed in the following section, a variant of anosognosia is commonly found in individuals with schizophrenia.

2.2.3. Concept of self

A person's concept of self develops at around two years of age, when the child shows mirror recognition of self and begins using pronouns such as "me" and "mine" (Amsterdam, 1972). Imaging studies have demonstrated "a midline network of posterior and anterior brain linking self-awareness and conscious experience" (Kjaer et al., 2002), specifically involving the prefrontal cortex, anterior cingulate, and superior and inferior parietal lobe. A PET study of individuals who were asked to describe their own personality showed activation of the angular gyrus in the IPL, the precuneus in the superior parietal lobe, and the orbitofrontal cortex (Kjaer et al., 2002). Another PET study, in which the person was asked to imagine themselves doing something, also showed activation primarily in the IPL (Ruby and Decety, 2001). A functional MRI study of self-face recognition activated the right supramarginal gyrus, inferior frontal lobule, and inferior occipital gyrus (Uddin et al., 2005); the authors concluded that the IPL "may be responsible for maintaining self-other distinctions across a variety of sensory modalities." Another fMRI study showed activation of the right temporoparietal junction, including the IPL, when the volunteers were providing a self-perspective. The authors concluded that "both functional imaging and neuropsychological data imply that the temporoparietal junction is involved in computing an egocentric reference frame" (Vogeley et al., 2001).

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Individuals with schizophrenia often experience disruptions in their sense of self, especially in the early stages of their illness (Sedman, 1970). This is referred to as depersonalization or derealization and illustrated by statements such as the following:

> "I have a strange ghostly feeling as if I am from another planet. I am almost nonexistent."

> "He was troubled by a strange, pervasive and a very distressing feeling of not really being present, or fully alive."

> "I have no consciousness."

> "My feeling of consciousness is fragmented." (Parnas and Handest, 2003)

A PET study of 8 individuals with feelings of depersonalization, compared to 24 controls, reported hyperactivity in the angular gyrus and hypoactivity in the superior and medial temporal gyri (Simeon et al., 2000). An extreme example of an impaired sense of self is rare individuals with schizophrenia who fail to recognize photographs of themselves (Faure, 1956).

One of the more dramatic disruptions of the sense of self is the feeling that "one's thoughts or actions are being influenced or replaced by those of an external agent (e.g., a spirit or a machine)" (Spence et al., 1997). Such feelings are referred to as delusions of passivity or alien control. Kurt Schneider listed this as being among the "first rank," or most clearly pathognomonic, symptoms of schizophrenia (Schneider, 1959). An fMRI study in which normal controls were led to believe that another person was controlling their actions reported associated activation of the IPL (Farrer and Frith, 2002).

Several studies have linked delusions of passivity in individuals with schizophrenia to the IPL. In one of the MRI structural studies referred to above, individuals with schizophrenia who had passivity delusions were compared to those who did not have passivity delusions; the former group had significant reductions in gray matter volume in the right supramarginal gyrus and the left prefrontal region (Maruff et al., 2005). A PET scan study compared 7 individuals with schizophrenia with passivity delusions, 6 without such delusions, and 6 normal controls; the passivity delusions were associated with hyperactivation of the right supramarginal gyrus and cingulate gyrus (Spence et al., 1997). Such studies have led to the conclusion that "passivity phenomena in schizophrenia may be associated with *hyperactivity* in the parietal cortex, perhaps lateralized to the right hemisphere" (Dankert et al., 2004).

The most important disruption of self in individuals with schizophrenia is an unawareness of their illness, which occurs, to a varying degree, in approximately half of all patients (Amador et al., 1994; Dickerson et al., 1997). This is a variant of anosognosia, described above, except that the lack of awareness is for a psychiatric condition rather than a neurological condition. Given the known importance of IPL function in determining sense of self, it would be predicted that IPL function would be impaired in individuals with schizophrenia who lack awareness of their illness. The few studies that have been done, using neuroimaging and neuropsychological measures, have yielded conflicting results. There is reasonably strong evidence that the prefrontal cortex is involved (Larøi et al., 2000; Flashman et al., 2001) and some evidence for parietal lobe involvement (McEvoy et al., 1996); given the strong connection between the two, it is likely that anosognosia in schizophrenia involves both areas. Thus, one review of these studies concluded that "unawareness of illness in psychosis may be due to abnormality of prefrontal and parietal cortices and their associated cortical and subcortical neural pathways" (Flashman and Roth, 2004). This is consistent with the earlier observations of Denny-Brown and Chambers (1958) that the most prominent feature of parietal lobe function "is alteration in behavior with varying degrees of unawareness of the behavioral defect."

Related to a person's concept of self is the person's ability to infer mental states in other individuals, widely referred to as "theory of mind." Neuroanatomically, this ability is thought to involve a neural network including the IPL, the anterior cingulate, and other selected areas of the frontal and temporal lobes (Brüne and Brüne-Cohrs, 2006). Brüne (2005) has reviewed many studies suggesting that individuals with schizophrenia are impaired in their "theory of mind."

2.2.4. Executive functions

Executive functions are widely considered to be primarily associated with the prefrontal cortex. As Goldman-Rakic (1988) has noted, however, "neither the functions nor organization of prefrontal cortex can be understood without reference to its connections with other structures," including the parietal cortex. Multiple executive functions, such as the Wisconsin Card Sort Test, have been shown to activate the IPL in addition to prefrontal areas (Wang et al., 2001; Buchsbaum et al., 2005). It is thus possible that the executive functions impaired in individuals with schizophrenia are impaired because of dysfunction in the IPL as well as the prefrontal cortex.

Sustained attention, known to be impaired in many individuals with schizophrenia, is another example. Mesulam and Geschwind (1978) noted that "a lesion in the inferior parietal lobule may result in a similar disconnection of cortex from the limbic system" and produce attention deficits. An MRI study of neuroleptic-naïve individuals with schizophrenia using the Continuous Performance Test (CPT) as a measure of sustained attention reported significant correlations between CPT performance and gray matter volume in the left supramarginal and angular gyri, among other regions (Salgado-Pineda et al., 2003); the authors concluded that these regions "may be involved in the attentional impairment strongly linked to the illness."

Working memory, also known to be impaired in schizophrenia, also involves the IPL. Using functional MRI, Kindermann et al. (2004) reported a "diminished WM [working memory] response in schizophrenia patients in the left supramarginal gyrus (BA 40)" as well as in other regions. Jansma et al. (2004) also carried out a functional MRI study of working memory in schizophrenia and found that the supramarginal gyrus was bilaterally involved. They concluded that working memory dysfunction in schizophrenia is the result of an impaired functional output of the whole WM [working memory] system… rather than of selective pathology of the DLPFC."

A third functional MRI working memory study found significantly greater activation in the left IPL of persons with schizophrenia compared to controls (Thermenos et al., 2005). Kim et al. (2003), using PET imaging to study working memory in schizophrenia, reported that activation of the supramarginal gyrus bilaterally correlated with activation of the right prefrontal area in the normal controls but not in individuals with schizophrenia, suggesting dysfunction in the parietofrontal neural network. Finally, Barch and Csernansky (2007) reported differential fMRI activation during working memory tasks in the "dorsal parietal cortexes" in 57 individuals with schizophrenia compared to 120 normal controls.

There are additional executive functions known to involve the IPL. Dual-task management, which many individuals with schizophrenia find difficult, has been shown to involve the supramarginal gyrus as well as the prefrontal cortex (Collette et al., 2005). And in an fMRI study of decision-making in individuals with schizophrenia, the supramarginal gyrus was activated significantly more in the patients than in the controls (Paulus et al., 2002). The authors concluded that "these results support the hypothesis of a prefrontal–parietal cortex dysfunction during decision-making in schizophrenia patients."

3. Discussion

This review suggests that the IPL may play a significant role in schizophrenia. In retrospect, this is not surprising, since symptoms of psychosis, including delusions and hallucinations, have been observed in individuals with strokes in the temporoparietal region (Levine and Finkelstein, 1982) as well as in individuals with parietal lobe epilepsy (Salanova et al., 1995; Ishii et al., 2006).

It is also of interest that the superior temporal gyrus (BA 22) is immediately contiguous to both the supramarginal and angular gyri, since auditory hallucinations have been linked to dysfunction of the superior temporal gyrus (Pearlson, 1997; Dierks et al., 1999; Bentaleb et al., 2001). In addition, it is thought that the supramarginal gyrus receives auditory inputs (Eccles, 1989), and the IPL has been reported to be activated during novel auditory stimuli (Kiehl et al., 2001) and auditory hallucinations (Cohen and Green, 1995). Since the histology of these Brodmann areas is similar, it is reasonable to hypothesize that pathology in any one of these areas could involve others that are adjacent.

It is also interesting to speculate whether different clinical syndromes in schizophrenia may primarily involve different brain areas. An fMRI study of deficit syndrome schizophrenia reported decreased activation of the supramarginal gyrus (Lahti et al., 2001). Similarly, a PET study of individuals with "psychomotor poverty syndrome" schizophrenia (decrease in speech, movement, and expression of affect) found decreased blood flow in the supramarginal and angular gyri (Liddle et al., 1992). It thus seems possible that the specific symptomatology of any given patient may be determined by the relative degree of pathology to specific components in the prefrontal–temporal–inferior parietal axis.

It thus appears that the IPL deserves more attention from schizophrenia researchers. In this regard the Stanley Medical Research Institute (SMRI) is making available to researchers a new collection of postmortem brain tissue from the IPL. The initial tissue consists of sucrose-fixed sections from the supramarginal and angular gyri (BA 40 and 39). The left IPL (15 individuals with schizophrenia) and right IPL (10 individuals with schizophrenia) have been matched with an equal number of unaffected controls by age, sex, race, RNA quality, pH, storage time, and side of brain, for a total of 50 brains. In the future, we plan to offer another IPL collection of frozen tissue. Details of this new collection and applications for the tissue are available on the SMRI website: www.stanleyresearch.org.

In addition to neuropathological studies, additional imaging studies should be carried out of both gray and white matter. Especially important will be imaging studies that include multiple components of the schizophrenia brain network and the connections between them, which need to be more clearly defined. Additional studies of IPL function are also needed, including those focusing on aspects of sensory integration, body image, concept of self, and executive function. For example, subsets of patients with schizophrenia with altered pain thresholds, distortions of body image, or anosognosia could be compared with patients without these manifestations. Also interesting will be studies of specificity, in which individuals with schizophrenia are compared with those with bipolar disorder with psychotic features and/or those with major depression with psychotic features. Such studies will determine whether the IPL abnormalities and the schizophrenia network dysfunction are specific to schizophrenia or are applicable to psychotic disorders in general.

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Contributors

E. Fuller Torrey is the sole author of the manuscript.

Conflict of interest

The author has no conflict of interest.

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