Motor and Somatosensory Conversion Disorder: A Functional Unawareness Syndrome?

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Although conversion disorder is closely connected to the origins of neurology and psychiatry, it remains poorly understood. In this article, the authors discuss neural and clinical parallels between lesional unawareness disorders and unilateral motor and somatosensory conversion disorder, emphasizing functional neuroimaging/disease correlates. Authors suggest that a functional-unawareness neurobiological framework, mediated by right hemisphere-lateralized, large-scale brain network dysfunction, may play a significant role in the neurobiology of conversion disorder. The perigenual anterior cingulate and the posterior parietal cortices are detailed as important in disease pathophysiology. Further investigations will refine the functional-unawareness concept, clarify the role of affective circuits, and delineate the process through which functional neurologic symptoms emerge.

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Conversion disorder is a neuropsychiatric condition at the interface of neurology and psychiatry. Clinically trained neurologists see approximately 30% of outpatients for medically unexplained illness,[1] and up to 18% of patients with unexplained illness are diagnosed with functional neurologic symptoms.[2] Despite frequent clinical exposure to conversion disorder, after identifying functional signs, including distractibility and inconsistency, without objective deficits, neurologists are uncomfortable in the psychiatrist's chair.[3] The lack of a conceptual framework through which to understand this disorder is exemplified by a neurologist's stating "Well, I don't really know….I suppose it may be their way of dealing with problems they can't solve"[3]. It is the collective clinical experience of the authors that part of the challenge for physicians in working with these patients lies in the absence of an accepted neurobiological framework through which to understand the clinical phenotype of functional neurological symptoms.

Advanced functional neuroimaging techniques now allow access to neural-system dysfunction in conversion disorder. Despite multiple neuroimaging studies and reviews on the topic,[4] a brain-based conceptual model through which to understand functional neurological

disturbances has yet to be recognized. In this article, conversion disorder is first historically contextualized to allow for the integration of neurologic and psychiatric concepts with an emerging neurobiology. Second, the neurobiology of the disorder is explored by reviewing functional neuroimaging findings in the most well-studied subset of patients (functional unilateral motor and somatosensory disturbances). Thereafter, conversion disorder is positioned among the "unawareness" disorders in neuropsychiatry, and *functional unawareness* is suggested as a useful neurobiological framework through which to understand this illness.

In this article, the newly proposed Diagnostic and Statistical Manual of Mental Disorders (DSM-5) nomenclature is adopted, and conversion disorder is referred to as functional neurological disorder (FND).[5]

APPROACH

The purpose of this article is to offer a neurobiological perspective through which clinicians and translational scientists may begin to understand patients with functional unilateral motor and somatosensory disturbances, rather than provide a comprehensive review of published neuroimaging studies on this enigmatic disease. To this end, we searched PubMed and Google Scholar for relevant articles in "conversion disorder" and "hysteria" published between January 1995 and December 2010; emphasis was placed on articles using Technetium-99 single photon-emission computed tomography (^{99}Tc-SPECT), fluorodeoxy-glucose positron emission tomography (FDG-PET), and functional magnetic resonance imaging (fMRI) techniques. Analyses exploring hypnosis or feigning behaviors in comparison to FND were omitted, to limit comparisons between FND and additional incompletely-understood biological phenomena.

HISTORICAL PERSPECTIVE: ORIGINS OF HYSTERIA

FND was first known in the medical literature as "hysteria," and it has engaged prominent individuals in the history of medicine, neurology, and psychiatry. Although initially described in ancient Greece with gynecologic ("wandering womb") themes and later as demonic possession after the rise of Christian civilization,[6] hysteria was medicalized in the 19th century by the French neurologist Jean-Martin Charcot, through his study of patients at the Salpêtrière Hospital. Charcot recognized hysteria as an acceptable, neurologically diagnosable condition, stating "the neurological tree has its branches; neurasthenia, hysteria, epilepsy, all the types of mental conditions, progressive paralysis, gait ataxia."[7]

Reclassification of hysteria as a psychiatric disorder began with the writings of Sigmund Freud, an Austrian neurologist and founder of psychoanalysis. Freud argued, "the aetiology was to be sought in sexual factors."[8] He coined the term "conversion hysteria" and described a process whereby "the affective idea is converted into a physical phenomenon."[8] Whereas Freud described a transformation of psychic conflict into somatic symptoms, Pierre Janet, a French psychologist, suggested that "hysteria is a form of mental depression characterized by retraction of the field of personal consciousness and a tendency to the *dissociation* and emancipation of the system of ideas and functions that constitute personality."[9] Thus, by the late 19th/early 20th century, FND was an accepted neurologic and psychiatric condition.

The FND clinical syndrome is now recognized to occur more often in women, with symptom onset often presenting during the teens or early-20s. Patients have an elevated rate of Axis I comorbidity, and symptoms are generally acute in onset, of short duration with multiple reoccurrences, and commonly occur after a psychological stress. As originally described by Freud, patients may exhibit an unusually calm demeanor regarding their symptoms ("la belle indifférence"), whereas others exhibit a high degree of emotionality. Childhood sexual and physical trauma may be reported. In functional weakness, movements, if performed, are slow, tentative, and non-sustained. Functional somatosensory deficits may manifest with nonphysiological demarcations, such as immediately left of the sternum, or may exhibit fluctuating boundaries.

Neural formulations of FND have emerged in the last few decades. Whitlock, in 1967, described hysteria as a neuropsychiatric disorder involving attentional dysregulation, characterized by "selective depression of awareness of a bodily function."[10] Sierra and Berrios, in 1999, proposed altered attention and awareness, mediated in part by inferior parietal cortex dysfunction, as a neurobiological model for FND.[11] Lateralized right-hemispheric dysfunction with relative preservation of a narrative, interpretative left hemisphere, has also been suggested as a neural explanation for FND, and implies an overlap with delusional disorders.[12,13] Also, theories applied to the broader category of somatoform disorders have

emphasized affect dysregulation and somatic amplification as important mediators of disease.[14,15]

NEUROIMAGING OF UNILATERAL MOTOR/ SOMATOSENSORY FND

Over the past 10–15 years, the neurobiology of unilateral motor and somatosensory functional neurologic disturbances has advanced with the use of functional neuroimaging techniques, including ^{99}Tc-SPECT, FDG-PET, and fMRI. Prefrontal inhibition of primary motor/ somatosensory cortex,[16–19] intentional disturbances,[20,21] attentional dysregulation,[22–24] impaired action authorship recognition,[25] and affective disturbances[26,27] are major neural processes implicated in the neuroscience of FND.

Inhibition
The first published neuroimaging study in FND was performed on a 32-year-old woman with panic attacks, depression, and recent marital discord, who developed left-sided weakness (preserved finger movements, with arm weakness and foot clumsiness) and paresthesias.[18] ^{99}Tc-SPECT blood flow patterns in response to left median nerve stimulation revealed right frontal cortex hyperperfusion and right parietal cortex (including primary somatosensory cortex) hypoperfusion, only during symptomatic periods. In related studies, medial prefrontal cortex (PFC) hyperactivation was replicated and further localized to the anterior cingulate cortex (ACC), orbitofrontal cortex (OFC), and ventromedial PFC.[16,17,19] Medial PFC inhibition of unimodal primary somatosensory and motor cortices was postulated to explain functional numbness and weakness.[17,18]

Intention
Impairment in the generation of motor intention was also hypothesized for patients with FND.[20] Three men with functional arm weakness (two, left-sided) and previous depression exhibited left dorsolateral PFC hypometabolism compared with healthy subjects on FDG-PET during performance of joy stick movements. Functional weakness was suggested to reflect a disturbance in motor intention planning. This notion has been supported by evidence of altered functional connectivity between the dorsolateral PFC and sensorimotor areas in patients with FND,[21] and further delineation of a role for the dorsolateral PFC in motor intention generation and cognitive control of motor behavior.[28,29]

Attention
A third neurocognitive function, attention, was explored, using ^{99}Tc-SPECT in seven patients with functional unilateral hemiparesis/hypoesthesia (4, left-sided; 5, with depressed mood) during rest and passive bilateral vibratory stimulation.[24] Contralateral thalamic and basal-ganglia blood-flow reductions were observed only in symptomatic patients during sensory stimulation. Impairments in striato-thalamic components of attentional and motivational neural networks were proposed as mediators of FND. Also, in related investigations,[30] patients with unilateral motor FND exhibited bilateral striatal/pallidal and right-thalamic volume reductions. Thalamic dysfunction was replicated in functional anesthesia,[23] and a lack of striato-thalamic circuit activation was also found in patients with functional weakness.[19]

In a unique case, a 56-year-old, right-handed woman with emotional distress related to marital discord presented with transient functional left arm and leg weakness, hypoesthesia *and* functional left-hemispatial neglect.[31] fMRI obtained while she was symptomatic, during performance of a line-bisection task, showed right ACC hyperactivity relative to healthy subjects. Thus the perigenual ACC (pACC), posterior parietal cortex (PPC),[18] striatum, and thalamus, regions implicated in attentional neurobiology, exhibited dysfunctional activity in FND patients.

Action Authorship
Disturbances of motor intention awareness and self-agency have also been suggested for patients with FND. Voon and colleagues[25] examined fMRI blood-oxygen level-dependent (BOLD) patterns in eight FND patients (two with major depression, three with generalized anxiety disorder) with positional, predominantly unilateral, unexplained tremors as compared with volitional movements. The right temporoparietal junction (TPJ) was less active during unexplained movements, and reduced functional connectivity occurred between the right TPJ and bilateral sensory/motor cortex, ACC, medial PFC, and right superior parietal lobule. Given the roles of the TPJ and adjacent regions (PPC/superior temporal gyrus) in motor intention awareness and self-agency perception,[32–35] diminished right TPJ activity and aberrant connectivity were suggested to explain FND patients' inability to recognize themselves as the authors of their actions.

Affective Disturbances
Two imaging studies directly probed affective (limbic) circuit dysfunction in FND patients. A scripted, traumatic

memory provocation fMRI study was administered to a woman with selective amnesia for a romantic break-up and functional right hemiparesis/hypoesthesia. fMRI showed right amygdala, ACC, parietal cortex, and inferior frontal activations during cued recall of repressed memories, as compared with readily-recalled events.[26] Amygdalar activation was proposed as a bio-marker of heightened emotional salience for repressed memories. A second fMRI study examined affective facial processing in 16 mixed-phenotype, hyperkinetic, FND patients with anxiety and depression, compared with healthy subjects. Patients with hyperkinetic FND showed increased amygdalar activation to happy faces and increased amygdalar functional connectivity with the supplementary motor area (SMA).[27] Motor disinhi-bition resulting from heightened limbic–SMA interac-tions via striato-pallidal-thalamic projections were proposed as mechanisms of limbic influences on motor actions.[25] These studies supported the idea of amygda-lar and ACC dysfunction in patients with FND.

Having reviewed prefrontal-mediated inhibition, in-tentional disturbances, inattention, impaired action-authorship recognition, and affective dysregulation as major neural processes implicated in the neurobiology of functional neurologic disturbances, the following section frames unilateral functional motor and somatosensory disturbances as "disorders of unawareness."

UNAWARENESS AND RIGHT-HEMISPHERE DYSFUNCTION

The neglect syndrome is defined as a right-brain/left-body unawareness disorder characterized by impaired ability to report, respond, or orient to novel or salient stimuli; it is associated with right-hemispheric lesions.[36,37] Subtypes include sensory (somatosensory, visual, audi-tory), motor, hemispatial, and personal neglect.[38] Of particular interest is motor neglect, characterized by impaired motor intention generation and exemplified by limb underuse, hypokinesia, and inability to sustain motor movements (motor impersistence), despite the absence of corticospinal system damage.[38,39] Notably, functional weakness resembles motor neglect. Struc-tural studies in motor-neglect stroke patients identify a pattern of right hemisphere-predominant frontal, parietal, striatal and thalamic lesions,[40–44] and implicate cortico-cortical (frontal-parietal) and cortico-subcortical pathways in lesional motor neglect.

Concepts related to motor neglect include motor intention awareness (the conscious recognition of the desire to move) and self-agency (the sense that we are the authors of our own movements).[34] Early behavioral studies examining predictions of motor action[45] and hand position[46] suggested that individuals used internal sensory predictions to anticipate motor actions, a process termed forward modeling or corollary discharge.[32,45–47] Forward modeling allows the central nervous system to maintain accurate performance based on the predicted sensory consequences before the actual processing of sensory afferent signals. Furthermore, observations have shown that the predictability of sensory consequences following motor actions correlates with perceived self-agency.[48] Forward modeling, awareness of motor in-tention, and self-agency may be related concepts that involve common or interrelated neural circuits. Also, aberrant forward modeling has been extended to other modalities and proposed as an explanation for neuro-psychiatric disturbances, including auditory hallucina-tions and delusions of control in schizophrenic patients experiencing their own internal dialogue or actions as "other."[47]

A role for the PPC in forward modeling has been suggested by lesional and functional neuroimaging studies. Lesions of the superior parietal lobule have been linked to time-dependent decrements in sustained arm motor function and proprioceptive unawareness,[49] and updates of limb posture recruited bilateral superior parietal cortex activations in an fMRI spatial-pointing task.[50] These results supported a role for the PPC, particularly the superior parietal lobule, in real-time dynamic internal sensorimotor integration, a prerequi-site for predictive forward-modeling.

Studies also implicated the PPC in motor intention awareness and self-agency. Patients with right inferior parietal lobule (IPL) lesions exhibited a shortened latency between conscious recognition of impending action and motor execution. This suggested a deficit in motor intention awareness before the imminent release of motor action.[34,35] Interestingly, patients undergoing intraoper-ative IPL cortical stimulation experienced the conscious desire for motor action at low intensity and an experience of motor accomplishment at high intensity.[33] This implied that perception of action authorship involved similar neural networks to that of motor intention awareness. In further support of this concept, patients with IPL lesions falsely attributed examiner-made, complex hand movements as their own,[51] and bilateral angular gyrus

activations occurred in individuals making agency determinations.[52] Thus, the PPC, a node in the large-scale brain network disturbed in lesional neglect (including motor neglect), participates in forward-modeling, motor-intention awareness, and self-agency perceptions.[34,53,54]

Somatosensory neglect (e.g. tactile extinction to double simultaneous stimulation in the absence of lateralized somatosensory deficits) is difficult to isolate clinically, and frequently coexists with primary somatosensory disturbances, motor weakness, and hemispatial neglect, limiting its study in isolation. However, extrapolation from hemispatial neglect, the most studied neglect syndrome subtype, allows an inference into the neurobiology of somatosensory unawareness. Primarily on the basis of lesional analyses, a distributed, right hemisphere dominant, cortical and subcortical network for hemispatial neglect has been suggested to include the PPC, TPJ, superior temporal gyrus, ACC, frontal eye fields, inferior frontal gyrus, striatum, and thalamus.[55–63] Somatosensory and motor neglect, therefore, may share similar neural substrates.

FND: A FUNCTIONAL UNAWARENESS SYNDROME

Functional neural circuit disturbances in motor and somatosensory FND overlap with the cortico-cortical and cortico-subcortical pathways implicated in lesional motor and somatosensory neglect. A number of cross paradigm studies in patients with functional limb weakness demonstrated patterns of neural dysfunction in right-greater-than-left PPC (extended to include the TPJ),[18,25] ACC,[17,26,64] striatum, and thalamus.[19] Functional neuroimaging studies in patients with functional somatosensory deficits exhibited similar dysfunction in attentional regions, again including right-greater-than-left parietal cortex,[18] ACC,[17,23,26,31] striatum,[24] and thalamus.[23,24] In further support of an overlapping neural substrate between FND and lesional motor and somatosensory unawareness, a case of transient functional left-of-midline hemibody anesthesia was described in a patient with a right parietal infarct.[65] Psychogenic non-epileptic seizures may occur more often in patients with right-hemispheric lesions or right-hemispheric dysfunction on electroencephalogram.[66] Lastly, left-sided bodily deficits have traditionally been considered more frequent in FND,[67] although a recent metaanalysis failed to show this effect.[68]

Using a best-fit approach to synthesize neuroimaging and phenomenological data, *functional somatosensory unawareness* and *functional motor unawareness* are suggested as major contributors in the pathophysiology of unilateral somatosensory and motor related FND (Figure 1). Clinical and neural features of functional disturbances share a common denominator with lesional neglect: unawareness. Individual variation across unilateral motor and somatosensory FND phenotypes may be accounted for, in part, by relative contributions of prefrontal, posterior parietal, and subcortical components. Furthermore, pACC-subcortical and PPC-subcortical pathways may provide complementary, but distinct, unawareness contributions.[69,70] Disturbances of motivated behavior/motor control/affect regulation may arise preferentially from pACC–subcortical pathways (including pACC–amygdalar circuits), whereas attentional and perceptual miscalculations may arise from PPC–subcortical dysfunction.[69,71–73] Reciprocal cortico–cortical connections among the pACC, PPC, and dorsolateral PFC facilitate interactions among circuits mediating affect regulation, awareness, intention, and cognitive control.[74,75]

In this conceptualization, in addition to the PPC, an important role is postulated for the pACC in functional motor/somatosensory neglect, given its dual cognitive and emotional functions mediated by structural connections with the posterior parietal, premotor, dorsolateral prefrontal, OFC, subgenual ACC (sgACC), and medial-temporal cortices.[76–80] Human and animal models also implicate the ACC in stress-related, maladaptive experience-dependent neuroplastic change. For example, patients with posttraumatic stress disorder (PTSD) after childhood sexual trauma exhibited functional and morphologic abnormalities in the ACC, as compared with healthy subjects.[81,82] Chronic stress in animal models induced dendritic spine reduction in the ACC and hippocampus, with parallel enhanced dendritic arborization in the amygdala.[83,84] Reciprocal top-down (ACC) and bottom-up (amygdala) sites of aberrant experience-dependent neuroplastic change, and medial/lateral and dorsal/ventral PFC interactions specific to FND patients require more exploration in the context of extended emotional/affective regulation–neural circuit explorations (Figure 2). Furthermore, the OFC, implicated in social-emotional evaluation and behavioral control in the context of changing contingencies,[85] and the sgACC, implicated in the modulation of automatic emotional behavior,[86] are additional paralimbic regions that require

**FIGURE 1. Suggested Functional-Unawareness Neural Circuit Framework**
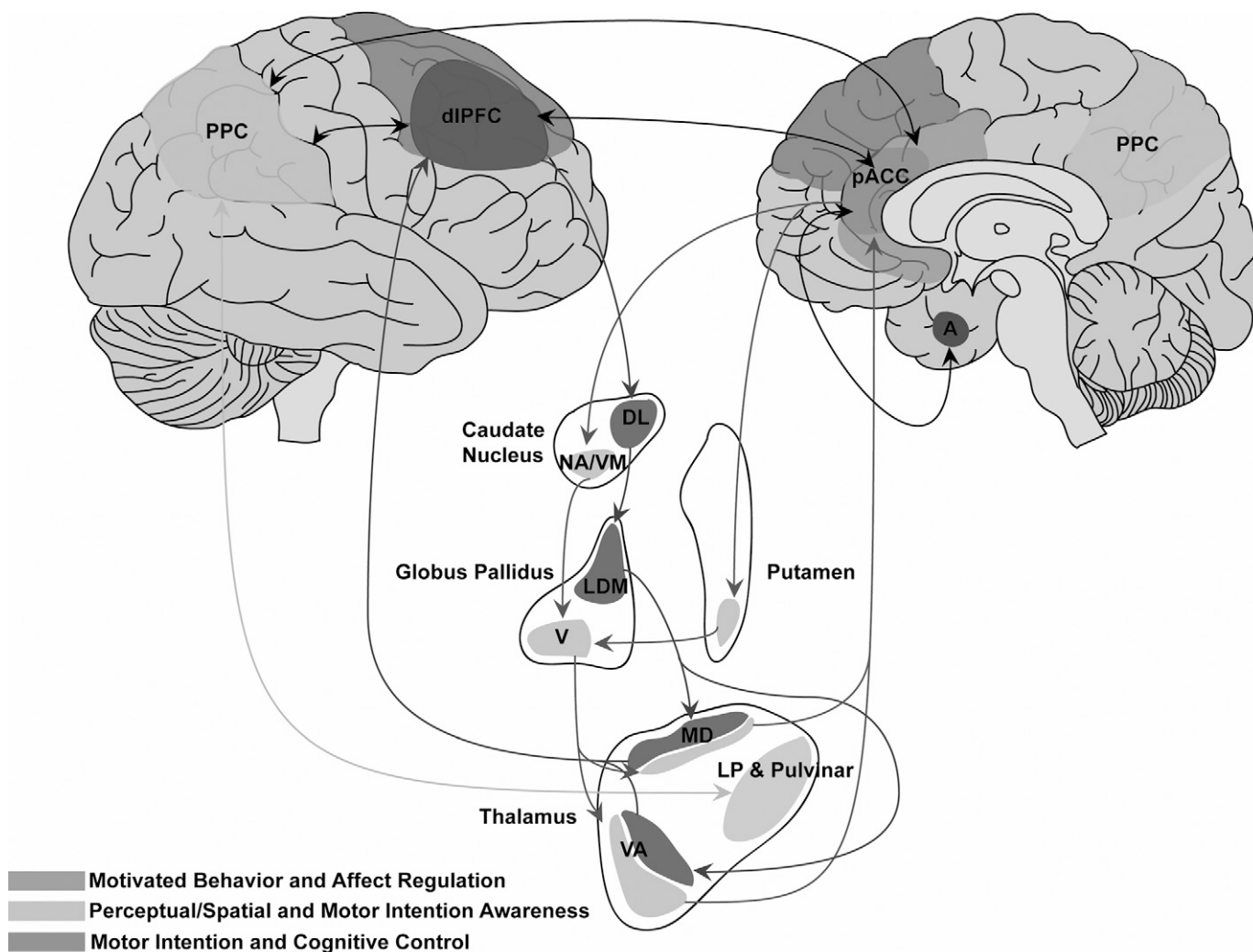
Dysfunction in the perigenual anterior cingulate cortex (pACC) and its subcortical connections (including reciprocal cingulate–amygdalar connections) results preferentially in impaired motivated behavior, motor control, and/or affect regulation. Dysfunction in posterior parietal cortex (PCC) and its subcortical connections results preferentially in impaired spatial and perceptual awareness, including aberrant forward modeling, motor intention awareness, and/or self-agency. Reciprocal cortico–cortical connections among the pACC, PCC, and the dorsolateral prefrontal cortex (dlPFC) facilitate interactions between awareness and intentional, cognitive control circuits.

VM: ventromedial; DL: dorsolateral; NA: nucleus accumbens; VA: ventral anterior; LP: lateral posterior; MD: mediodorsal; LDM: lateral dorsomedial; V: ventral; A: amygdala.

further investigation. Initial findings, nonetheless, position the pACC and related networks as mediators of impaired affect-regulation and cognitive processes in patients with FND.

Several important implications arise from the proposed neurobiological framework. The outlined cortico-cortical and cortical-subcortical pathways allow clinicians to understand the presentation of functional symptoms independent from notions of psychic tension and the unconscious mind; functional deficits in-and-of-themselves may not necessarily be symbolic of the particular emotional stress experienced by the patient, but rather may be the product of intrinsic neural connectivity patterns. Thus, the basic *form* or phenotype in which functional symptoms present may be driven by intrinsic neural connections, whereas the specific *context* of functional symptoms (i.e., why and when symptoms occur) may be a product of interactions between the patients' psychosocial stressors and attentional, limbic/paralimbic, and sensory-motor cortices.

FIGURE 2.   Extended Affective Regulation Neural Circuitry Requiring More Investigation in Patients With FND.
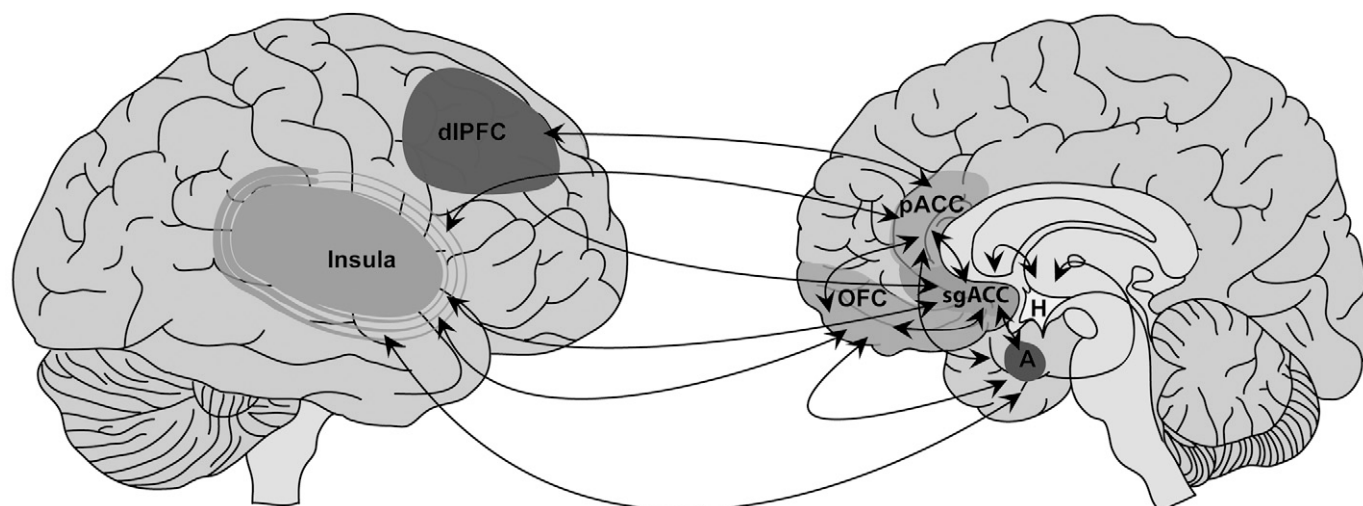
Reciprocal connections are outlined among the perigenual anterior cingulate cortex (pACC), subgenual ACC (sgACC), orbitofrontal cortex (OFC), dorsolateral prefrontal cortex (dlPFC), insula, amygdala (A), and hypothalamus (H). Parallel ACC, dlPFC and OFC prefrontal-subcortical pathways (not shown) also require more exploration in the context of studies probing affective regulation in patients with functional neurological disorder (FND).

Also, neurologists are frequently frustrated by interactions with FND patients, since clinicians may view them as fabricating their symptoms. This frustration is markedly less when treating unawareness in right-hemisphere stroke patients with neglect. Conceptualizing unilateral functional motor and somatosensory deficits as *functional neglect* or unawareness, rather than willful deception or simulation, may improve the therapeutic alliance between physician and patient, and potentially increase the number of clinicians inclined to work longitudinally with FND patients. Importantly, this framework does not, in our opinion, undervalue the role of affective disturbances in the presentation of functional neurologic symptoms, but rather contextualizes the patients' presentation in terms readily understood by clinicians. Finally, the identification of cortical sites, including the PPC and the dorsolateral PFC, offers targets to investigate for their therapeutic intervention in patients with FND; these include the potential use of neuromodulation techniques (i.e., transcranial magnetic stimulation) to modify aberrant functional activation patterns.

FIXED, FALSE ILLNESS BELIEFS IN FND: A LEFT-HEMISPHERE DELUSION

Having suggested functional unawareness as a neurobiological framework through which to understand motor and somatosensory FND, inherent differences in right-brain/left-brain functionality may clarify the fixed beliefs held by FND patients regarding the nature of their illness. Investigations in split-brain patients identified a role for the left hemisphere in narrative, interpreter-like functions.[87] Together with evidence that right-hemisphere lesions predisposed to delusions,[88] right-hemisphere dysfunction with relative preservation of left lateralized function has been proposed as a neural basis of fixed, false beliefs, including delusional misidentification syndromes.[12,13] Unawareness driven predominantly by right-hemisphere dysfunction with preserved interpreter functions in the left hemisphere may result in a functional interhemispheric disconnection, and it helps explain the persistent, false beliefs held by FND patients regarding their disease.

FND AND DISSOCIATION: EMOTIONAL UNAWARENESS?

Using the functional unawareness concept, it is intriguing to emphasize *emotional unawareness* a century after Pierre Janet offered restriction of the field of consciousness (dissociation) as a theory through which to understand FND.[9] It has been suggested that the right hemisphere plays a dominant role in emotional expression, a concept supported by evidence linking right-hemisphere lesions

with flat affect, aprosody, and blunted autonomic responses.[89–91] Dissociative tendencies are also now well recognized in FND by use of standardized self-report scales such as the Dissociative Experience Scale.[64] Although specific neuroimaging studies correlating dissociative tendencies with functional activation patterns in patients with FND are lacking, studies in related conditions with high rates of dissociation, including depersonalization disorder[92] and PTSD,[93] suggest a role for the right PPC, particularly the precuneus, and the ACC in dissociative neurobiology. Direct exploration of dissociation and alexithymia in FND populations may help clarify mechanisms of emotional unawareness and impaired emotional expression.

LIMITATIONS AND OTHER CONSIDERATIONS

There are several important limitations to address regarding the suggested conceptual framework. The discussion is limited to unilateral functional motor and somatosensory disturbances and does not incorporate other FND subtypes, including astasia-abasia (functional gait disorder),[94] functional blindness,[95] and psychogenic non-epileptic seizures. All FND subtypes may not have the same mechanistic network explanations for distinct phenotypes, and research in these and other subtypes warrant further investigation. Also, many of the functional neuroimaging studies cited examine single cases[18,26,31] and case–control studies with a small number of subjects,[20,24,25] increasing the possibility of type I statistical errors. Negative affective disturbances were also not consistently controlled for methodologically across studies, suggesting potential confounds for the prefrontal, subcortical, and limbic findings.

Comparisons with deliberate feigning or hypnosis-induced functional disturbances are also omitted. Although deliberate feigning has been used as a comparison condition in some FND neuroimaging studies,[19,20,96] the neural correlates of feigning are not yet well understood, which adds increased difficulty when comparing the neural activation patterns to patients with FND. Hypnosis-related research is also not incorporated in the FND framework, since hypnosis requires more exploration, but we acknowledge the possibility of an overlap in the biology of hypnosis and FND.[97]

The functional-unawareness concept may also be interpreted with evolving psychological models. It is important, however, first to note that, when considering the integration of psychological and neural models, researchers should not necessarily search for the neural correlates of a given psychological concept, which may or may not be supported by empirical evidence. With this in consideration, one possible psychodynamic formulation invokes mechanisms of adaptive and maladaptive psychological defense.[98] Defense mechanisms are conceptualized as the ego's efforts to cope with psychological stress, and pathologic somatic-based defenses thought to be used by patients with FND would reduce transpsychic conflict through bodily displacement. The ACC has been implicated in emotional expression/regulation, maladaptive neuroplasticity, and conflict monitoring (cognitive neuroscience definition), and offers intriguing possibilities for integrative synthesis. However, more research is needed to fully integrate psychological and neurobiological concepts in patients with FND.

Conceptualization of FND as a disorder of unawareness also does not explain differences between hypokinetic and hyperkinetic functional motor symptoms. Inhibitory or disinhibitory effects of premotor regions (i.e., SMA) on primary motor cortices, and modulated by interactions with the PPC, dorsolateral PFC, and limbic/paralimbic regions, may help clarify phenotypic differences.[27,34] This may be analogous to differences in alien hand syndrome phenotypes; medial-frontal lesions result in hypermotor, foreign behaviors, whereas posterior variants present more commonly with disturbances of posture and levitation.[99] Also, further clarification is needed of the role of the left hemisphere in unawareness, as seen infrequently, for example, in left-hemisphere lesions resulting in contralesional visual-spatial neglect or unawareness of deficit in Wernicke's aphasia.[36,37] Lastly, this article reconciles many of the distinct and overlapping neural-circuit findings across paradigms in FND, but falls short of providing a unifying neurobiological model incorporating the entire body of unilateral motor and somatosensory FND literature.[96,100] More detailed understanding will require larger subject groups, multiparadigm neuroimaging studies (including neuroimaging at rest to explore default-mode network disturbances), and non-imaging, cross-disciplinary research to provide a fully integrative model.

CONCLUSIONS

In summary, FND has served an important role in the origins of both neurology and psychiatry. In this article,

we identify overlapping neural circuitry between lesional motor/somatosensory neglect and some forms of FND. *Functional motor unawareness* and *functional somatosensory unawareness* are suggested as conceptual frameworks through which to understand functional motor and somatosensory neurologic symptoms. Early postulations by Charcot delineating FND as a functional neurologic disorder and Janet's dissociation theory for unawareness in hysteria are supported by evolving FND neural circuit delineations. Increasingly well-characterized large-scale brain networks mediating cognitive and affective processes and modulated by experience-dependent neuroplasticity provide the foundation for a neurobiological conceptualization through which to understand functional neurologic disturbances. Further investigation is needed to test and refine the functional-unawareness concept, delineate the biological processes through which functional symptoms arise, and clarify the role of affective neural circuits in FND biology. Subsequent investigation and synthesis will enable the development of a unified model for functional neurologic disturbances.

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