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Somatotopy and bodily hallucinations

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Hallucinations are commonly defined as “perceptual experiences in the absence of sensory input”. Hallucinations, one of the major first-rank symptoms of schizophrenia (SZ) spectrum disorders, include bodily hallucinations (BH), which may encompass tactile, somatic, visceral, proprioceptive, kinesthetic, vestibular, coenesthetic, nociceptive, sexual or thermal experiences. Although the underlying mechanisms of BH have not been established, four neuroimaging case reports have preliminarily described likely pathophysiological correlates of BH (Bär et al., 2002; Geoffroy et al., 2012; Jardri et al., 2008; Shergill et al., 2001). According to these case reports, three patients had SZ (Bär et al., 2002; Jardri et al., 2008; Shergill et al., 2001) and the fourth patient had delusional parasitosis (Geoffroy et al., 2012). In each report, per-hallucinatory functional magnetic resonance imaging (fMRI) revealed increased functional activation of the somatosensory cortices during BH. Two fMRI raw datasets were made available by the authors after email contacts (Geoffroy et al., 2012; Jardri et al., 2008). Strikingly, poor overlaps were observed between the identified overactive areas when the available functional maps for BH were projected onto a unique normalized template (**Figure 1**).

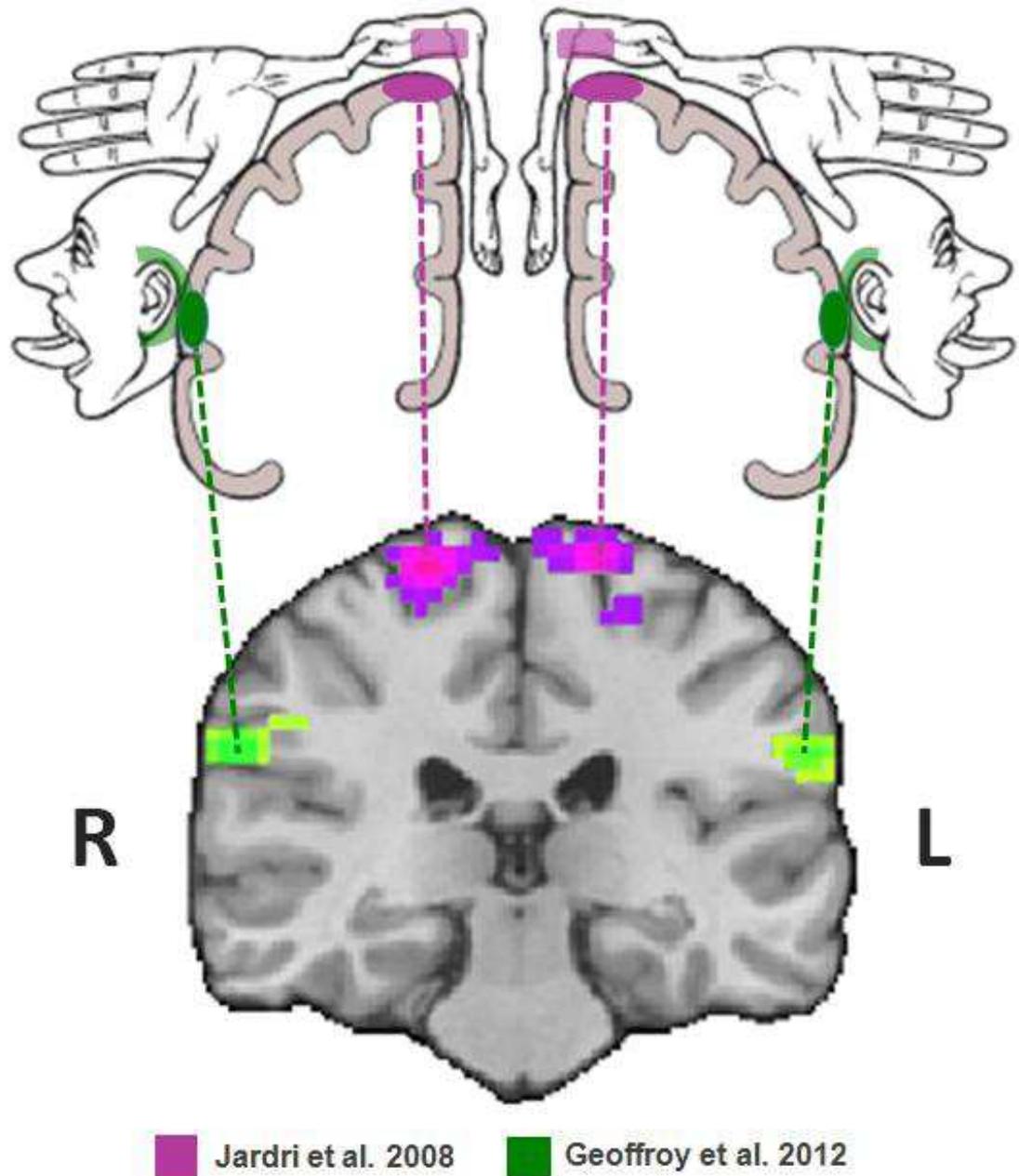


Figure 1. Functional brain activations during bodily hallucinations.

Per-hallucinatory functional magnetic resonance imaging (fMRI) findings were obtained from two published case reports of bodily hallucinations (BH) relative to the method described in the article by Jardri et al., 2013. These two functional maps were projected onto a unique normalized template. The Penfield sensory homunculus is presented above in the same coronal plane. Activations within the somatosensory cortex (z-maps with corrected $p < 10^{-4}$) were color-coded according to the reference paper (purple: Jardri et al., 2008; green: Geoffroy et al., 2012). Purple clusters were obtained from a patient who suffered from BH that manifested as “electric shocks” and alien “objects” moving inside his thorax, abdomen and pelvis. Green clusters were obtained from a patient who suffered from BH that manifested as “tingling” and “movement” sensations behind both ears from the temporal, mastoid and mandibular regions. The resulting cortical activations perfectly overlap the homunculus regions involved in sensations of the abdominal and temporal body parts.

This observation supports the concept that BH phenomenology is linked to the cortical somatotopic organization. This clinical-functional correspondence is interesting for several reasons. First, it allows the construction of a model that may account for BH beyond the conventional misattribution hypothesis, which was essentially developed in the auditory modality. The misattribution hypothesis stated that hallucinations might rely on the aberrant attribution of internal events to alien sources. However, although modality-specific hallucinations may share several common pathways, they may likely rely on specific neural dysfunctions transducing the hallucinatory content of the experience. Notably, this explanation has been suggested in case-reports of not only the visual hallucinations that are characteristic of Charles-Bonnet syndrome or schizophrenia but also multisensory hallucinations (Jardri et al., 2013).

Furthermore, we believe that the reported findings nicely highlight the potential contribution of case-reports towards the exploration of subjective experiences. **Figure 1** demonstrates how a specific functional pattern can be superimposed onto the somatotopic brain areas responsible for the body parts involved in the abnormal sensations that patients describe perceiving during BH. Because of the high inter-individual variability attributed to various possible hallucinations, group studies may suffer from two major shortcomings. First, group analyses usually reveal clusters formed by shared activated voxels across all of the participants. These clusters must survive thresholding strategies that are used to correct multiple comparisons in fMRI. The second point is directly linked to the first one because averaging the fMRI signal at the group level may result in an impoverished clinical-functional relationship revealed by the subject-level analysis (i.e., a somatotopic organization of BH). By illustrating two non-overlapping functional patterns linked with BH, **Figure 1** highlights the complementarities of case reports with group studies. These findings constitute the first step that must be confirmed in larger samples; however, the number is valid only if it is appropriately used. Grouping patients with BH would be futile if these hallucinatory experiences are not suitably assessed to constitute specific sub-populations. The likelihood that some BH experiences may be unique or limited to few patients must be considered.

The general argument that has been developed has nothing to do with a promotion of low statistical power in research on hallucinations, which may lead to erroneous conclusions and poor reproducibility. On the contrary, recent developments in fMRI technology has allowed for an exploration of these symptoms on a case-by-case basis, which may have significant bench-to-bedside implications. First, growing knowledge in this field has contributed toward reducing the stigma directed at patients suffering from hallucinations. Second, individual fMRI may contribute to innovative treatments for refractory BH, which for example facilitates identifying the

target over specific somatosensory areas during repetitive transcranial magnetic stimulation (rTMS) protocols (Jardri et al., 2008). The exact role that individual fMRI plays in assisting clinicians in decision-making, therapy and follow-up will need to be defined and adequately developed within the medical toolbox. However, this strategy may pave the way for personalized therapy in mental health.

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