Neuroscience 348 (2017) 288–301

SELF-FACE RECOGNITION SHARES BRAIN REGIONS ACTIVE DURING PROPRIOCEPTIVE ILLUSION IN THE RIGHT INFERIOR FRONTO-PARIETAL SUPERIOR LONGITUDINAL FASCICULUS III NETWORK

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Abstract—Proprioception is somatic sensation that allows us to sense and recognize position, posture, and their changes in our body parts. It pertains directly to oneself and may contribute to bodily awareness. Likewise, one's face is a symbol of oneself, so that visual self-face recognition directly contributes to the awareness of self as distinct from others. Recently, we showed that right-hemispheric dominant activity in the inferior fronto-parietal cortices, which are connected by the inferior branch of the superior longitudinal fasciculus (SLF III), is associated with proprioceptive illusion (awareness), in concert with sensorimotor activity. Herein, we tested the hypothesis that visual self-face recognition shares brain regions active during proprioceptive illusion in the right inferior fronto-parietal SLF III network. We scanned brain activity using functional magnetic resonance imaging while twenty-two right-handed healthy adults performed two tasks. One was a proprioceptive illusion task, where blindfolded participants experienced a proprioceptive illusion of right hand movement. The other was a visual self-face recognition task, where the participants judged whether an observed face was their own. We examined whether the self-face recognition and the proprioceptive illusion commonly activated the inferior fronto-parietal cortices connected by the SLF III in a right-hemispheric dominant manner. Despite the difference in sensory modality and in the body parts involved in the two tasks, both tasks activated the right inferior fronto-parietal cortices, which are likely connected by the SLF III, in a right-side dominant manner. Here we discuss possible roles for right inferior fronto-parietal activity in bodily awareness and self-awareness.

Key words: bodily awareness, proprioceptive illusion, right inferior fronto-parietal cortices, self-awareness, self-face recognition, superior longitudinal fasciculus.

INTRODUCTION

Proprioception is a somatic sensation that allows us to sense and recognize position, posture, and movements of our body parts, even when the eyes are closed. Thus, this sensation pertains directly to oneself, and cannot normally be shared with others, unlike vision and audition.

In our series of functional magnetic resonance imaging (fMRI) studies, we have consistently demonstrated that the cortical and subcortical sensorimotor cortices and the right inferior fronto-parietal cortices (in particular cytoarchitectonic areas 44 and 45, and area PF and its sub-regions) are recruited when blindfolded participants experience proprioceptive illusions of limb movement (changes in limb position or posture), even when the limbs are immobile (Naito et al., 2016). Compared to the sensorimotor cortices (Naito et al., 2016), the right inferior fronto-parietal cortices are less well understood.

The right inferior fronto-parietal cortices are usually more strongly activated when the participants

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Abbreviations: EPI, echo-planar imaging; fMRI, functional magnetic resonance imaging; FWE, family-wise error; FWHM, full-width-at-half-maximum; GLM, general linear model; MNI, Montreal Neurological Institute; pre-SMA, pre-supplementary motor area; ROI, region of interest; SLF, superior longitudinal fasciculus.

http://dx.doi.org/10.1016/j.neuroscience.2017.02.031

experience proprioceptive illusions than when they merely experience the cutaneous sensation that their limbs are vibrating (Naito et al., 2005, 2007; Amemiya and Naito, 2016). The right inferior fronto-parietal cortices are likely connected by the inferior branch of the superior longitudinal fasciculus tract (SLF III; Makris et al., 2005; Thiebaut de Schotten et al., 2011, 2012; Rojkova et al., 2015; Amemiya and Naito, 2016). In addition, the right inferior fronto-parietal regions that are active during the illusions are highly similar no matter whether the participants experience the illusions on their left or right hand or foot (Naito et al., 2007). Furthermore, activity in these regions usually had right-hemispheric dominance, even when the illusion is experienced at the right hand (Naito et al., 2005, 2007; Amemiya and Naito, 2016). Highly similar regions in the right inferior fronto-parietal cortices are also involved in visuo-proprioceptive multisensory processing, during which sighted participants recognize postural changes of the right hand by combining visual and proprioceptive information (Hagura et al., 2009). Most importantly, we have recently shown that the degree of right inferior fronto-parietal activity (cytoarchitectonic areas 44/45, and PF and its sub-regions) corresponds to subjective reports regarding the extent of the right hand illusion in blindfolded participants (Amemiya and Naito, 2016).

These lines of evidence indicate that the inferior fronto-parietal regions, which have blurred somatotopical representations and multisensory capability, appear to be involved in the proprioceptive awareness of "my limbs are moving" (changes in position or posture) in a right-hemispheric dominant manner. This view seems to be corroborated by other findings that robust right inferior fronto-parietal activity can only be observed in participants who experience reliable foot illusions (Cignetti et al., 2014), and that electrical stimulation to the human right inferior parietal cortex may elicit proprioceptive awareness of limb movements (Desmurget et al., 2009).

Another series of neuroimaging studies indicates that similar patterns of right inferior fronto-parietal activation have been reported when people visually recognize their own faces as distinct from others', irrespective of their familiarity (Sugiura et al., 2005, 2006, 2008; Uddin et al., 2005; Platek et al., 2006; Kaplan et al., 2008; Morita et al., 2008). One's face is a symbol of oneself (at least of the bodily self). Thus, visual self-face recognition directly contributes to recognition (awareness) of the bodily self, which is distinct from others. This may then lead to self-awareness (Gallup, 1982; Brooks-Gunn and Lewis, 1984).

On the other hand, as described above, proprioceptive signals are always derived from one's own body, and they may elicit bodily awareness regarding one's bodily posture and movements (proprioceptive awareness). We presume that this self-derived nature of proprioception may provide a basis that allows us to perceive ourselves as physically independent functional entities separate from other agents and the external world.

The right-side dominant activity of the inferior fronto-parietal cortices in the SLF III network during proprioceptive illusions (awareness) may provide the neuronal basis underlying bodily self-awareness, and hence, self-face recognition, which should be directly connected to bodily self-awareness, must also recruit these cortices connected by the SLF III tract in a right-side dominant manner. This may occur through the sharing of active brain regions in these cortices.

We scanned the brain activity of twenty-two healthy right-handed adult participants using fMRI while they performed both a proprioceptive illusion task and a self-face recognition task. In the former, we vibrated the tendon of the wrist extensor muscles of the relaxed right hand in blindfolded participants. In this case, the participants experienced a purely proprioceptive sensation of "my right wrist is flexing" based on the muscle spindle afferent inputs from the hand (Naito et al., 2016). In the latter, we presented visual images of the participant's own face and those of others' faces, and asked the participants to judge whether the face they saw was their own. Thus, this task required visual recognition of one's own face as distinct from others', which elicited visual awareness of "the face I see is my own".

We tested the hypothesis that both self-face recognition and proprioceptive illusion commonly activate the right inferior fronto-parietal cortices in the SLF III network regardless of differences in sensory modality (proprioceptive vs. visual) or body parts (limb vs. face). We also examined the right-hemispheric dominance in the brain regions active during the proprioceptive illusion and in those active during the self-face recognition separately. For anatomical identification of the brain activation patterns, we referred to the tract probability map, which describes the cortices most likely connected by the SLF I, II, and III tracts, and cytoarchitectonic probability maps of the human brain.

EXPERIMENTAL PROCEDURES

Participants

Twenty-two healthy right-handed adults (12 men and 10 women; age range, 18–47 years) participated in the study. All had normal vision or corrected-to-normal vision. The participants' right-handedness was confirmed using the Edinburgh Handedness Inventory (Oldfield, 1971). No participant had a history of neurological or psychiatric disorder. The protocol used for this study was approved by the ethics committees of the University of Fukui and the National Institute of Information and Communications Technology. We explained the details of the study to the participants before the start of the experiment. All participants provided written informed consent. The experiment was carried out following the principles and guidelines of the Declaration of Helsinki (1975).

Tasks

We used a proprioception illusion task and a self-face recognition task. The task order was randomized across participants. Before we started the fMRI experiment, we provided the participants with instructions. Every