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Research article

Supramarginal activity in interoceptive attention tasks

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HIGHLIGHTS

- Confirmed supramarginal (SM) activity in interoceptive attention/awareness (IAA).
- Activation patterns were similar for IAA regarding two body parts.
- Also performed group comparison analyses between IAA experts and novices.
- Results showed rather opposite profiles of SM activity for the two groups.
- SM is rather related to other aspect of attention, might be not essential for IAA.

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ABSTRACT

Interoceptive (feelings from inside organs) attention/awareness (IAA) is a body-related aspect of cognition that pursues homeostasis by detecting afferent signals, and there are practices aimed at focusing one's attention and awareness towards such feelings inside one's own body. There is a claim that these practices improve health which is one reason that neural correlates of such practices and IAA in general have been investigated in previous imaging studies. In several of these studies which used subjects with no or limited experience in IAA practices there was a report of supramarginal (SM) activity during IAA tasks, but the role of SM in IAA remain unclear. We first investigated if we could find similar results in novices, and if this activity is sensitive to the designated body part in the IAA task. We further investigated if these regions would be similarly recruited in subjects with extensive experience of IAA tasks while comparing results with a group of age and gender matched novices. Results in the novices replicated that of previous studies, and we showed this is the same for IAA tasks regarding two different parts of the body. Group comparison results showed opposite profiles of SM activation for the two groups; novices showed activation and the experts showed deactivation of the SM. The results suggest that novices recruit SM during IAA possibly due to lack of experience in those tasks but this could be alleviated for performing IAA as illustrated by activation profile in experts.

1. Introduction

Interoceptive (feelings from inside organs) attention/awareness (IAA) [1,2] is a body-related aspect of cognition that pursues homeostasis by detecting afferent signals, alerting to the existence of internal imbalances such as dehydration or injury to body organs. In fact, there are practices aimed at focusing one's attention and awareness towards such feelings inside one's own body with the claim of improving health [3–5], possibly through raising awareness to such internal body signals. There have been various studies discussing the important role of right insula in IAA [6,7].

Several of such neuroimaging studies have reported supramarginal (SM) recruitment, especially in the right hemisphere, during execution of IAA tasks [5,8–10], but this area has not gained much attention in the literature regarding IAA. Based on lesion and functional studies, the supramarginal gyrus (SM) has been reported

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to play a role in encoding peripersonal space [11,12] to form an egocentric representation of the corporeal self [13]. It has been suggested that the inferior parietal regions form a suitable hub for integrating sensory information across modalities [14]. The SM is located in this region of the brain and disruption of SM activity can cause impairments in various somatosensory-related cognitive functions, such as asomatognosia [15,16] and somatoparaphrenia [17], syndromes characterized by distorted awareness of the existence of a part of the body, or an 'out of body' experience [18–20]. Although this aspect of neural activity has been shown to play an important role in somatosensory [21] and motor functioning [18,22], its role in various cognitive functions regarding the body is still ambiguous.

It remains unclear why IAA induces SM activation as reported in those previous studie. As mentioned earlier, it has a role regarding attention/awareness towards peripersonal space, but this aspect of attention/awareness pursues homeostasis [12] from a rather exteroceptive perspective (i.e., avoiding harm from outside world), unlike IAA which pursues homeostasis from an interoceptive perspective. Therefore, although related, these two body-related aspects of attention/awareness could be dissociable. Intriguingly, studies on IAA that reported SM activation usually included subjects who were either total beginners in IAA practices or were beginners who had undergone a short training session in such practices. In fact, IAA places much emphasis on interoceptive feelings, and reliance on exteroceptive senses is usually minimized. Therefore, one reason for SM activation in those studies could be that beginners try to be aware of the existence of the attended-to body part from a rather exterocentive perspective and consequently recruit the SM. After long experience, this might be alleviated and subjects might not recruit SM anymore. In such case, we could expect less activation and possibly deactivation in these areas in experienced practitioners versus novices.

We first investigated IAA induced neural activations regarding two parts of the body (the knees and the lower abdominal areas) for subjects with no experience in IAA and confirmed similar activation patterns in SM and other brain regions as previous studies, for both designated body parts. We then performed a group comparison study with a group of expert IAA practitioners and a age/gender matched group of novices using the same IAA tasks.

Similar to previous studies on IAA, subjects were asked to attend to and be aware of sensations within their body parts. An important part of experiment set up in this study was that subjects were explicitly instructed to close their eyes while performing IAA tasks. This way, we can eliminate the possibility of SM activation as an effect of subjects directly attending to those body parts by visually attending to them and therefore, the reliance on the peripersonal information can be reduced. Thus, we can expect a more exclusive IAA performance especially in the experienced group. Although this is not unique to this study, we can better study the SM activity which has been majorly ignored in previous IAA studies.

2. Materials and methods

2.1. Participants

The experimental protocol was approved by the Ethics Committee of Tohoku University Graduate School of Medicine. Written informed consent was obtained from each subject.

First, we recruited Twenty-nine right-handed subjects (20 males, nine females) with a mean age of 52 (SD: 8) and with no previous experience with concentration, meditation, or similar techniques via advertisements in a local magazine.

For the group comparison study, we recruited 10 (9 males and 1 female) right-handed experienced practitioners (E group) with a mean age of 56.9 years (standard deviation, SD = 11.1 years) from the Institute of the Nishino Breathing Method. This method is one of the Kokyu-ho, or breathing method, styles where practitioners train focusing on breathing patterns and concentrating on their body parts. There are both practices where concentration is accompanied by body movements and practices without such movements. The group had an average of 16 (SD = 8.2) years of IAA experience; each subject had more than 3 years of experience, and had been practicing regularly during the last 6 months. Also, we chose a group of novices (N group) such that they would be age and gender matched with the expert group (mean age, 55.1; SD = 7.9 years).

All subjects were Japanese, and no subject had any history of neurological or psychiatric illness or any auditory problem.

2.2. Experimental overview

The experiment consisted of blocks comprising trials during which attention/awareness was directed to certain parts of the body and rest periods. The target body areas were the lower abdominal/upper pubic region, which is the focus of several East Asian meditation disciplines, and the knees, which are involved in movements. Subjects were tested under three conditions (each 24 s in duration): rest (R), attention to the lower abdominal region (L), and attention to the knees (K). Each condition commenced with a 0.5 s cue indicating its onset and the condition tested. The cue "rest" indicated that the subjects should not concentrate on any body part, whereas "knee" and "lower abdominal" indicated that the subjects should attend to their knees or lower abdominal/upper pubic region, respectively, and be aware of the sensations in the designated region. Each K or L condition was preceded by an R condition.

According to experienced IAA practitioners, it is easier for subjects to attend to areas of their body with their eyes closed. Thus, we presented all cues through headphones, and subjects were instructed to close their eyes during the experiment.

During the attention task, subjects were told to attend to and be aware of the sensations in the designated area. The order of L and K trials was counterbalanced across subjects. All subjects practiced the tasks for approximately 5 min prior to the start of the experiment until they verbally acknowledged that they understood the tasks. During the trials, subjects were instructed to return their focus to the task if they found themselves attending to other thoughts.

3. MRI data acquisition and preprocessing

This part has been described in details in the supplementary material.

3.1. Data analyses

After preprocessing, a general linear model (GLM) design matrix was constructed for each subject to model the onset and duration of each of the seven repetitions of the K and L conditions. First, a parameter estimate image was created for activation during each of the K and L conditions (K and L parameter maps).

Effects of interest were assessed in group-level random effects analyses using *t*-tests on contrast images generated from subject-specific analyses. These effects included activations (deactivations) for each condition and the sum of the conditions (K, L, and K + L) in each group (and also for the whole group of novices), higher activation in N compared to the E group for each condition, and the sum of the conditions (NK–EK, NL–EL, and N(K + L)–E(K + L)).

For the group comparison analyses we explored the analyses in a region of interest (ROI) including the bilateral supramarginal gyri (SM).

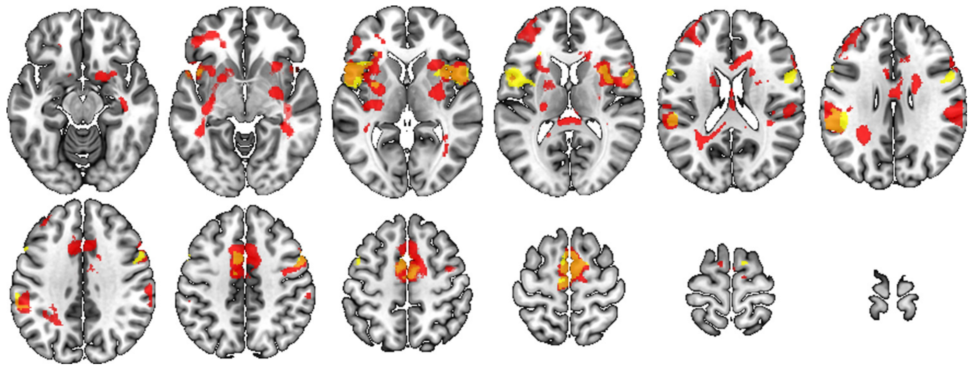

Fig. 1. Activation pattern for the novices, activations for L condition are depicted in red and activations for K condition are depicted in yellow.(For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

For all the analyses voxels were first assessed at the $p < 0.005$ (uncorrected) level, and clusters corrected for multiple comparison ($p < 0.05$, FWE; larger than 4725 mm^3) were reported as significant clusters. Also, for the group analyses, voxels passing the corrected height threshold ($p < 0.05$, FWE) inside the SM areas (defined by the AAL [23] atlas included in the [24] WFU PickAtlas toolbox) are reported in the results.

We also performed Group independent component analysis (gICA) on the experts brain activities to explore if the SM deactivity would appear on some sort of task negative component, and conversely, if insula would appear as a task positive network component. The functional MRI data for subjects was entered into GIFT toolbox (http://mialab.mrn.org/software/) in matlab, and components were extracted by ICA decomposition using the infomax algorithm. In this analysis the number of components was restricted to 20, and for each component the maps were transformed into *z*-score maps. Each independent component consists of a spatial map and an associated timecourse. Finally, the components were sorted based on their correlation with the task time courses. Here, we only focused on the components containing the right insula and supramarginal gyrus.

4. Results

Similar to previous studies we found activations in supramarginal areas (bilateral), insula (bilateral), supplementary motor cortex (bilateral) and right precentral gyrus in the novices. Fig. 1 illustrates the activations for L and K conditions separately. As it can be seen, there is a similar activation pattern for both conditions while right SM activation is more pronounced in K, however this was not of significance.

For the subgroup of novices in the group comparison analyses (the K + L condition in the N group) the activations were similar to those mentioned above, including areas such as bilateral insula and supplementary motor area. There were also significant activations in bilateral SM. Table 1 summarizes the results for significant clusters. For those significant clusters, the *t*-value for peak activation is also indicated, as well as if this value passes the FWE corrected 5% significance (depicted by *). Similar activation patterns were observed in the K and L conditions separately.

For the E group there was significant deactivation in the right SM, cuneus, precuneus, bilateral middle/superior temporal gyrus and right fusiform gyrus (Supplementary material Fig. 1). The deactivations in SM area are illustrated in Fig. 2a and Table 1, but there was no activation in the SM areas even when the thresholds were markedly lowered (uncorrected voxel-wise threshold of $p < 0.05$ uncorrected, extent threshold of a single voxel).

Novices showed higher activation of the right SM, middle cingulate cortex and left inferior oppercular/triangular frontal (Supplementary material Fig. 1), than the experienced subjects (N(K + L)–E(K + L)). The results in SM region for this contrast are depicted in Fig. 2a and Table 1. Across this cluster, the E and N groups showed opposite activation profiles; the E group showed deactivation and the N group showed activation (Fig. 2b). Again, similar phenomena could be observed for each of the K and L conditions separately, but the results were not statistically significant.

The independent component analyses (ICA) revealed a task positive component (positively correlating with task time courses) including insula, majorly in the right hemisphere, and a task negative component including SM (Supplementary material Fig. 2). Both components were among the components with high correlations with task time courses, 5th and 3rd respectively among 20 components.

5. Discussion

Results in novices replicated those of previous studies on IAA, and showed SM activation for IAA regarding two distinct parts of the body. In the group comparison analyses there was an opposite activation profile in the SM region of novices and experienced practitioners performing IAA.

The results replicate the activation patterns of SM reported in previous studies on novices performing IAA. Conversely, several previous studies of interoceptive attention/awareness towards one's own heartbeat [7], [25] did not report such activation. One possible explanation could be that being aware of one's own heartbeat could be easier than awareness of other organs of the body, such as the ones used in the tasks of the current study. Thus, even inexperienced subjects do not feel the need to recruit SM for awareness of their egocentric body representations for attending to

Table 1
Brain activity patterns within the ROI.

Area	MNI peak coordinates (mm)			*t* value	Size
	x	*y*	*z*		
Activation for N(K + L)					
Left SM	57	34	24	4.49*	650
Right SM	54	28	24	4.13*	667
Deactivation for E(K + L)					
Right SM	62	46	24	3.59	546
N(K + L) – E(K + L)					
Right SM	66	−28	25	3.89*	880
Decrease in activation across trials for novices					
Right SM	53	−34	39	4.31*	532

Cluster peak expressed as the *t* value. 'Size' indicates the cluster size in mm^3.
* Denotes that the peak was significant for the height (FWE corrected, $p < 0.05$).

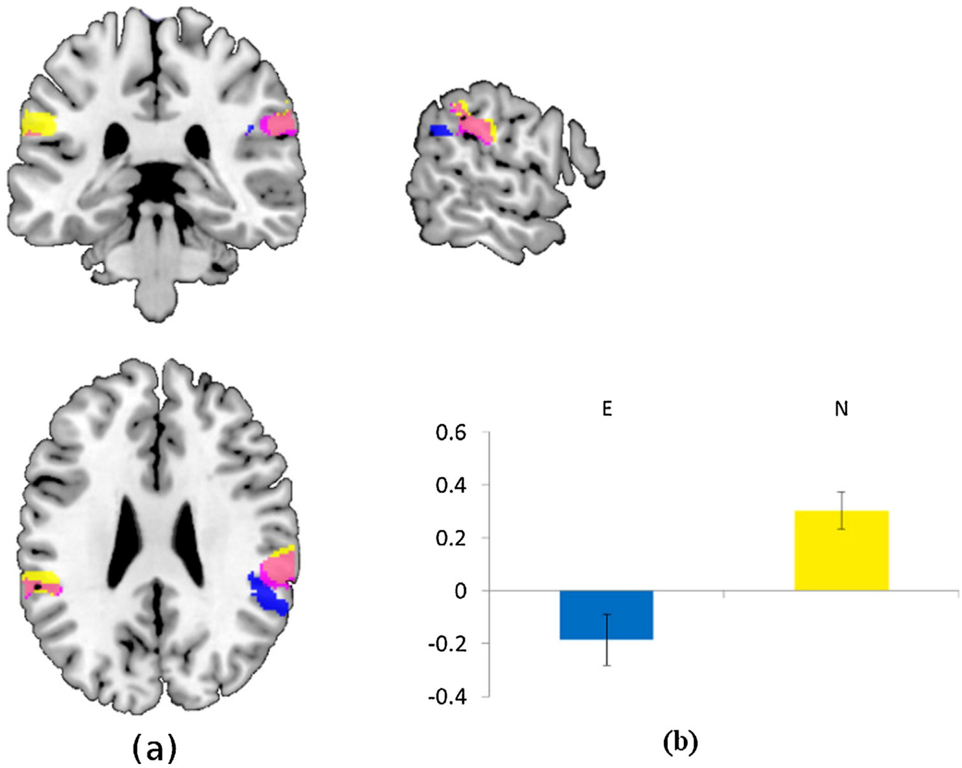

Fig. 2. Activation patterns in the SM regions. (a) Activation in the N group (yellow), less activation in the E versus the N group (violet), and deactivation in the E group (blue). The results in the left SM, belonging to non-significant clusters are also illustrated. (b) Activation profile for the cluster in the right SM showing significantly less activation in the E versus the N group (the cluster in the right SM depicted as violet in (a)).(For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

their visceral senses (or attention reorienting/inhibition, discussed later).

The most interesting aspect of our results is that the activation pattern was significantly different in experienced IAA practitioners; there was a cluster of significant deactivation in the posterior right SM and significantly less activation, compared to novices, in the anterior aspect of the SM. Across the latter cluster, novices showed activation and experienced practitioners showed deactivation. These results clearly show an opposite effect on SM recruitment in the two groups, which appears to be the result of years of IAA practice. As mentioned in the introduction, it can be suggested that, when focusing on inner interoceptive sensations, the experienced group paid less attention to outward and exterocentive peripersonal information and thus the related region became deactivated. One other possibility for difference in activation patterns of SM in the two groups might be related to the role of SM in attention reorientation/inhibition [26,27]. This might mean that experts and novices just have different strategies for attention orientation: Novices need to repeatedly reorient their attention from spontaneous thoughts toward interoceptive sensations and consequently recruit SM, while experts might be in a phase of focused attention which requires deactivation of SM to avoid reorienting attention toward distractors as discussed in [26].

An additional aspect of the results is right lateralization. Both the activation in the novices and the deactivation in the experienced subjects were more pronounced in the right SM than the left SM. Based on both possibilities discussed earlier this could be expected; the right SM has been reported to be the neural coder of peripersonal space and corporeal awareness [11,13,18,19,28–30], also its role in attention reorienting/inhibition is often with right side dominancy [26,27]. Interestingly, most studies on SM activation during IAA have reported right-lateralized results [5,8–10].

Novices showed significant activation of insular cortex in agreement with previous studies, but no such significant activation was found for experts. However, novices did not show significantly higher activation in this region compared to experts as in the case for supramarginal area, and we can not conclude any significant differences between the two groups in this area. Moreover, the ICA revealed a task positive component overlapping insula (mainly in the right hemisphere), and a task negative component in SM. These results suggest that both groups are similar in insula recruitment, but have obvious differences in SM activations, and as mentioned earlier there might be at least two possible reasons for this difference.

It is worth to note the activation of insula especially in the right hemisphere is quite expected, since this has been the case in various previous studies on interoception or IAA. Craig [6] determined that the primate lamina I spino-thalamocortical pathway projection into the insular cortex provides a primary interoceptive representation of the physiological condition of the body, particularly in the non-dominant hemisphere, and various studies have reported results consistent with this argument [7,31]. These reports suggest that the R-insula is the main center of the brain for interoception. Craig later claimed that these interoceptive signals as well as signals regarding emotions are further processed in the anterior division of insula to form awareness of feelings at each immediate moment, and in this regard, insula includes a buffer for such moment-by-moment awareness [31]. Interestingly, "being in the present" is a concept strongly emphasized in almost all attention/concentration disciplines.

In total, the results suggest that SM recruitment is not directly related to IAA per se, but rather is related to other aspects of attention. We presented two possibilities regarding the reason for observed SM response patterns in experts and novices; however, the current experiment design does not let favoring one possibility over the other.

One major drawback of this study is that there is no clear way to determine whether the participants were actually compliant in the tasks. Actually, this problem also existed in other studies regarding IAA in which no outward stimulation was included. Therefore, we suggest this issue to be taken into account for future studies on this topic.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.neulet.2015.01.031.

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