ABSTRACT

Objectives: Progressive muscle relaxation (PMR) is one of the self-management relaxation techniques that can be used in the general population and patients with specific issues. However, no study to date has revealed the brain activity associated with PMR. Therefore, we assessed the changes in brain activity induced by PMR using functional magnetic resonance imaging (fMRI).

Design and setting: We conducted an intervention study with PMR and control sessions. The subjects were twelve healthy adult men who had no prior experience of PMR.

Interventions: Subjects performed a control session in which muscles were repeatedly simply tensed and relaxed. Subsequently, a PMR session took place, during which muscle tension was reduced through a systematic procedure of tensing and relaxing of muscle groups combined with structured breathing.

Main outcome measures: We identified and visualised brain activity based on individual and group-level analysis of fMRI data.

Results: Eleven subjects' data were analysed. In the control session, brain activity broadly changed, while the change was limited to specific parts of the cerebral cortex and limbic system in the PMR session. PMR gradually decreased activity in the superior frontal gyrus (SFG), inferior frontal gyrus (IFG), and posterior cingulate cortex (PCC). In a region of interest (ROI) analysis, interactions between sessions were observed in the putamen, anterior cingulate cortex (ACC), postcentral gyrus (PCG), and insula.

Conclusions: That PMR led to few areas showing changed activity suggests that the technique may suppress brain activity. Even novices may be able to induce such a focused mental state.

INTRODUCTION

Progressive muscle relaxation (PMR) is a self-management relaxation technique developed by Jacobsen in 1938.[1] PMR can enable a deep state of relaxation via repeated tensing and relaxing of muscle groups combined with breathing exercises.[1] PMR has been used to control stress, not only in the general population without mental and physical problems, but also in patient populations. PMR has shown benefits in reducing anxiety and depression, improving sleep quality, alleviating fatigue and reducing pain.[1-3]

Several studies have examined temporal changes in brain activity during PMR. Lee et al.[4] used electroencephalography (EEG) in chemotherapy patients assigned to one of two randomised groups, namely a PMR group and a music therapy group. Their data demonstrated that theta band activity increased in the posterior area, despite decreased beta band activity in the medial frontal area during PMR and music therapy. Further, in the music therapy group, alpha band activity decreased in comparison with the PMR group. However, EEG records electrical activity via multiple electrodes placed on the scalp: therefore, it is difficult to detect the electrical activity in the deeper parts of the brain. Pifarre´ et al.[5] assessed brain activity using 18F-fluorodeoxyglucoseon-positron emission tomography (18F-FDG-PET) in patients with cancer, comparing changes in activity among PMR, drug treatment with diazepam, and no intervention groups. Both the PMR and the drug treatment groups showed a significant decrease in glucose consumption in the cortex compared to the no-intervention group. PET detects molecular activity within the body; however, its use should be limited

to severely or specifically ill patients because of the associated radiation and the invasiveness of the procedure.

Functional magnetic resonance imaging (fMRI), which is non-invasive and non-radioactive, is able to detect brain activity induced by various stimuli with high temporal and spatial resolution. A number of fMRI studies have reported changes in brain activity induced by complementary therapies such as meditation and yoga.[6, 7] However, no study to date has assessed changes in brain activity engendered by PMR. Accordingly, the objective of our study was to assess the brain activations induced by the PMR using fMRI.

MATERIALS AND METHODS

Subjects

Twelve males participated in this study. All gave written, informed consent to take part in this study. The subjects had no history of head injury, learning disability, or psychiatric illness. All subjects had no prior experience of any relaxation techniques. The study was approved by the local Institutional Review Board of Gunma University Graduate School of Medicine.

Experimental Interventions

We compared PMR and control sessions to assess the effects of PMR. All subjects experienced both the PMR session and the control session.

PMR session: PMR is a self-guided stress management technique that reduces muscle tension through a systematic procedure of tensing and relaxing muscle groups combined with breathing

exercises.[8] The PMR procedure of this study was adopted from Jacobson's PMR and adjusted to accommodate the fMRI body position (i.e., to stabilise the head position) by omitting the cephalic muscles, facial muscles, and cervical muscles from the exercise. Subjects were instructed to close their eyes, after which they alternately tensed and relaxed groups of muscles in a prescribed sequence. Subjects inhaled slowly through their nose when tensing their muscles, held their breath, and then exhaled a long thin breath through their mouth when relaxing, and were encouraged to gradually feel their bodily changes throughout the tensing/relaxing cycle. Concurrently, PMR instructions were provided via headphones.

Control session: Subjects cyclically tensed and relaxed their muscles. Subjects were instructed to close their eyes and to repeatedly tense and relax the muscle groups in a prescribed sequence. The muscle groups were same as those used in the PMR session. However, the subjects were not instructed to pay attention to their breaths and could relax their muscles during a breath. To avoid focusing their performance and attention in any way, we did not provide specific instructions. Throughout the control session, subjects listened to instructions regarding the control session via headphones.

Before each session commenced, subjects were provided with an explanation of the procedure, and practiced their performance of it in a private room. The order of performance was blocked; the first block was the control session, and the second the PMR session, to avoid knowledge of PMR influencing performance of the control task. There was a one-hour break between sessions.

MRI acquisition

Image scanning was performed on a 3 T scanning system (MAGNETOM Trio, A Tim System; Siemens, Tokyo, Japan) at the Brain Activity Imaging Center (Kyoto, Japan). A forehead pad was used to stabilise the head position.

A T2-weighted gradient-echo echo-planar imaging sequence was used with the following parameters: repetition time (TR) = 3000 ms, echo time (TE) = 30 ms, flip angle = 80°, matrix size = 64 × 64, 50 slices, voxel size = 3 × 3 × 3 mm. A T1-weighted high-resolution anatomical image was obtained using a magnetization-prepared rapid acquisition with gradient-echo (MPRAGE) sequence (TR = 2250 ms, TE = 3.06 ms, flip angle = 9°, field of view = 256 × 256 mm, matrix =256 × 256, 208 slices, voxel size = 1 × 1 × 1 mm).

Image analysis

Image and statistical analyses were performed using the statistical parametric mapping package SPM8 (http://www.fil.ion.ucl.ac.uk/spm) implemented in MATLAB Version 7 (The MathWorks Inc., Natick, MA, USA). Functional images within each run were realigned using the first scan as a reference, to correct for head movements. Then, T1 anatomical images were coregistered to the first scan of the functional images. Following this, the coregistered T1 anatomical image was normalised to a standard space, as defined by the Montreal Neurological Institute (MNI).[9] These spatially normalised functional images were resampled and smoothed with an isotopic Gaussian kernel (8 × 8 × 8 mm).

This block design was subjected to random effects analyses. First, the primary analysis used the

general linear model. Both the PMR session and the control session consisted of four blocks of eight trials, with rest periods present before and after each block (pre-rest, post-rest; Fig.1).

To assess time-wise effects by using parametric contrasts, an autoregressive model was used. Each block was modelled as a box-car function, convoluted with a canonical haemodynamic response function. We used the parametric contrasts estimated via the linear trends to assess whether brain activity varied over time. Then, the subject-specific contrast images of parameter estimates were used as inputs to the second (random effects) level of analysis, using a one-sample t-test based on the summary statistics. Planned T-contrasts were performed to assess brain regions in which activity changed over time. Significantly activated voxels were identified using a threshold of $P < 0.001$ (uncorrected), and $Z \geq 3.4$ at the voxel level. To assess differences in activation patterns between PMR and control sessions, we performed region of interest (ROI) analyses. The ROIs consisted of seventeen areas, defined on the basis of the whole brain analysis. The percent signal changes were derived from the voxels within a 10 mm radius sphere centred at the peak of each area. Single-subject analyses were performed for each session, the pre-rest, and the post-rest, against the baseline using Marsbar Toolbox Version 0.43 (http://marsbar.sourceforge.net/). The percent signal changes were assessed with two-way (pre-rest vs post-rest or PMR session vs control session) repeated-measures analyses of variance (ANOVA). We used Bonferroni correction to adjust for multiple comparisons. Analyses were conducted with IBM SPSS statistical software (version 18.0). *P*-values of 0.05 were considered statistically significant.

RESULTS

We enrolled twelve healthy males. One participant's data were excluded from the analysis because his MRI revealed abnormal lesions in his left temporal lobe. Thus, the data of eleven participants (median age 27, range 22–33) were analysed in this study.

Whole brain analysis

In order to detect the changes in brain activity induced by PMR and control conditions, we first used whole-brain analysis of each session. Figure 2 illustrates via glass brains the regions in which activity was statistically increased during the control and PMR sessions. In the control session, numerous, dispersed regions showed increased activity, whereas the regions showing increased activity were more limited in their dispersal in the PMR session. Decreased brain activities are shown via glass brains in Figure 3. In both the control and PMR sessions, decreased activities were observed in a smaller area as compared with the increased areas of activity. Table 1 indicates brain regions, cluster sizes, and intensities of significantly changed brain activities in both sessions. The control session elicited increased activity in various regions, including the superior temporal gyrus (STG), parts of the basal nucleus, the middle frontal gyrus, anterior cingulate cortex (ACC), insula, and postcentral gyrus. In contrast, the PMR session only induced a significant increase in the bilateral STG. In the control session, significantly decreased activity was found in the parahippocampal gyrus, caudate nucleus, and middle temporal gyrus, whereas the PMR session led to decreases in the superior frontal gyrus (SFG), inferior frontal gyrus (IFG), and posterior cingulate cortex (PCC).

ROI analyses

To find differences in activation patterns between PMR and control sessions, we used ROI analysis. Percent signal change data were calculated for seventeen areas, which were based on the results of whole brain analysis. Session (control and PMR) × time (pre and post) repeated-measures ANOVAs for the seventeen areas indicated five significant interactions, consisting of the right putamen ($F_{1,20}$ = 20.02, $P < 0.001$), left putamen ($F_{1,20}$ = 19.09, $P < 0.001$), right ACC ($F_{1,20}$ = 17.59, $P < 0.001$), left postcentral gyrus (PCG; $F_{1,20}$ = 14.27, $P = 0.001$), and right insula ($F_{1,20}$ = 12.33, $P = 0.002$). Furthermore, for all five areas, in the control session, the percent signal change increased during the post-rest. In contrast, for PMR, the percent signal change decreased. These areas are illustrated in Figure 4. Additionally, Table 2 shows the percent signal changes with reference to baseline (pre-rest data) in different brain regions.

DISCUSSION

Several studies have assessed brain activity during PMR. Pifarre´ et al.[5] examined brain activity using 18F-FDG-PET, comparing changes in activity among PMR, drug treatment with diazepam, and no intervention groups. In PMR and diazepam groups, areas which presented a greater decrease in 18F-FDG uptake included the frontal cortex, anterior cingulate cortex, and insula. Lee et al.[4] used EEG to study a group of patients undergoing chemotherapy. Among PMR, music therapy, and control groups, EEG data demonstrated that PMR and music therapy treatments were associated with an increase in posterior theta-band activity and a decrease in midfrontal beta-band activity. Studies that

use EEG, such as Lee et al., can show changes in brain activity in real time during PMR. However, the brain regions involved cannot necessarily be precisely located. By using fMRI, we observed the locations of brain activity during PMR in detail.

We compared control and PMR conditions to assess differential brain activity patterns for PMR. The muscle tensing actions of control and PMR conditions were same. However, the muscle relaxation performances were different. It is noteworthy that simply a difference in muscle relaxation technique led to differences in brain activity between conditions.

Fewer brain regions changed activation in the PMR versus control condition. In the PMR sessions, brain activity changed only in small parts of the cerebral cortex and limbic system. However, brain activity in the control condition increased throughout the cerebral cortex, limbic system, and basal ganglia.

A previous study reported that beginner meditators activated more brain regions than experienced meditators during mindfulness meditation.[10] Kozasa et al.[11] showed that regular meditators activated fewer brain regions than non-meditators during an attentional task. In a study of pain processing, Kakigi et al.[12] noted that when a yoga master was in a non-meditative state, brain activity was greater than in a meditative state. They suggested that during meditation, brain activity may be unaffected by emotions and stimulation. Our result that few brain regions changed in activity during PMR is consistent with the aforementioned findings that experienced meditators exhibit less profound brain activity changes than beginners. Thus, the PMR performance of repeatedly tensing and relaxing

muscles may suppress brain activity and induce a state that is resistant to environmental conditions.

The whole-brain analysis showed that activity of the SFG, IFG, and PCC significantly decreased during PMR. The SFG is implicated in inhibitory neural networks and self-awareness[13, 14], whereas the IFG plays a role in working memory, attention, and cognitive focus.[15, 16] Nakata et al.[14] assessed brain activity during somatosensory go/no-go paradigms in healthy subjects. Activation of the SFG did not change during go-trials, but in no-go trials, its activity was suppressed. Moreover, the study of sensorimotor processes has revealed deactivation of the SFG in categorization tasks, even though it is activated in introspection tasks.[13] The researchers noted that the SFG region was responsible for the negative blood oxygen level dependent (BOLD) effect in inhibitory processing, which occurred independently the required response. This deactivation of the SFG is useful to suppress self-awareness and to prevent distracting activity. How do the results of our study compare with the outcomes of meditation research? Several studies of meditation have also noted deactivation of the SFG and IFG. Manna et al.[16] compared the brain activity of novices and experts during meditation. They found deactivation of the SFG and IFG in the expert group, but not in the novice group. Our results and these novice-group results are in conflict; our results were similar to the outcome of the expert group. Manna el al. suggested that sustaining attentional focus in meditation implies deactivation of the SFG and IFG. Therefore, in our study, the decrease in activity of these regions in the PMR session might reflect focus on the muscle relaxation component of PMR. We also observed that activity of the PCC significantly decreased during PMR, whereas during the control task, PCC activity did not

significantly change. The PCC plays a central role in the default mode network (DMN), which consists of areas that are more active during the resting state than during task performance.[17, 18] The PCC is particularly responsive to external stimuli and is implicated in episodic memory processing.[18, 19] Michael et al.[18] reported that healthy subjects demonstrate a relatively active PCC during the resting state. However, when performing a working memory task they showed relative deactivation of the PCC compared to baseline. Similarly, in our study, we found a decrease in PCC activation and no change within other DMN areas during PMR. These patterns of brain activation make clear that the PMR task of relaxing muscles is distinct from a general state of rest. Furthermore, beyond studies of cognition, previous studies of meditation and relaxation techniques have reported deactivation of the PCC region. Garrison et al.[20] showed deactivation of the PCC in expert meditators during meditation, whereas novices showed activity in this area. The researchers described the sensory experiences of "undistracted awareness" or "effortless doing" as associated with PCC deactivation.[20, 21] In addition, in their study, a few novices also exhibited decreasing PCC activation over repeated meditations. PMR not only directs consciousness toward breathing, but is also characterised by somatic sensations such as that of muscle relaxation. Previous studies that support our results have described the sensation of "losing oneself"; that is, focusing on relaxing muscles and breathing, and not being distracted by awareness, feelings, or thoughts. In contrast, few studies have reported activation of the PCC area. In a study of mindfulness-based stress reduction (MBSR) versus a control task consisting of the random generation of numbers, significant signal increase was observed in the PCC during the

onset of MBSR in comparison with the control task.[22] The proposed explanation was that the PCC is inhibited in MBSR in favour of maintaining focus on the present moment. Hölze et al.[23] reported a study of healthy individuals who were assigned to MBSR and no-intervention groups. Exploratory analyses identified increases in grey matter concentration in regions in the PCC during MBSR, but not in the no-intervention condition. Our results differed from these aforementioned study results. PMR and MBSR are similar in that they are both relaxation or stress management techniques. However, MBSR does not involve recognizing feelings and body sensations. Therefore, attentional differences might influence activation of the PCC.

In the ROI analysis, interactions between the control and PMR sessions were observed in the ACC, insula, putamen, and PCG, which indicates that there were differences in brain activity changes between the control and PMR sessions in these regions. Interestingly, an opposing pattern of changes was common to the regions: the percent signal change increased after the control session, while it decreased after the PMR session. What led to these different results, given that both conditions consisted of different ways to relax muscles? The putamen, which is known to form a part of the motor network, is also involved in the attention.[24] Given that the percent signal change in the putamen altered in the period without bodily action, it is reasonable to conclude that attentional role of the putamen, rather its motor network role, underlies this result. The ACC plays an important role in the attentional network,[25] and is involved in performance monitoring, control functions, and response conflict.[26,27] Accordingly, several studies have reported activity change in the ACC during

meditation.[28] The insula is highly involved in the neural networks implicated in emotional experiences and control, as well in the processing of pain.[22] Previous studies of attention-related neural networks have reported that in novice meditators, activity in attentional areas, including the ACC, increases during meditation. Dickenson et al.[29] assessed the neural mechanisms underlying a brief mindfulness episode in healthy, novice mindfulness meditators. Significant increases in activity were found in regions involved in attentional networks. The researchers suggested that in early stages of mindfulness meditation practice, a simple mindfulness induction recruits neural regions associated with attentional engagement[30]. The subjects in our study were beginners at PMR. However, we obtained a decrease in the percent signal change in the ACC during the PMR session. Ives-Deliperi et al.[31] reported that the blood oxygenation level dependent (BOLD) signal decreased in the ACC and insula during MBSR; however, they did not conduct a comparative analysis with control conditions. Another study reported that in performing meditation, activity increased in the ACC and IFG in beginners, while it decreased in experienced individuals. Manna et al.[16] suggested that the increase in these regions in beginners during meditation, where attention is not explicitly directed in the process, resulted from efforts to pay attention and reflect. Taylor et al.[10] showed that less change in activity in the ACC was observed in experienced individuals versus beginners at meditation. In addition, Lutzl et al.[32] stated that when concentrating during thought, the activity of the attentional neural system decreases in experienced individuals. Repeatedly attending to the site of muscle relaxation in PMR may have engendered the reduction in activity in these areas. The activity of the primary

somatosensory area and L-PCG increased in the control session. A state where attention was directed toward the surroundings may have continued during the control session. It is presumed that even beginners were able to perform intending to “feel a sense of relaxation” (i.e., the muscle relaxation component of PMR) without resistance, and consequently, the signals in the areas involved in the attentional network did not increase. In addition, based on the signal change in the insula, conditions that were not easily affected by emotions or stimuli were presumably fostered in PMR. Meditation training is known to allow self-control, independent of emotions and thoughts. Therefore, repeating the bodily actions during the muscle relaxation period in PMR may have induced a state wherein cerebral activity subsided, and which was not easily affected by the immediate environment.

The usefulness of PMR has been tested in psychological disorders including panic disorder, generalized anxiety disorder, and depression[1, 33, 34]. Further, the study of anxiety disorders has benefitted from functional neuroimaging approaches. For example, such disorders are associated with activity changes in the insula, amygdala, and ACC, each of which plays a role in the experience and regulation of emotion[35, 36]. We demonstrated that PMR potentially reduces brain activity, which may explain why PMR provides benefits to individuals with psychological disorders, i.e., through modulating cerebral activity.

Finally, limitations of this study should be noted. First, the number of subjects was small and limited to healthy males. We chose such subjects to obtain basic data regarding changes in brain activity during the performance of PMR; however, as such, the results of this study do not necessarily

apply to females or patient populations. Due to the broad application of PMR, further studies focusing on correspondingly broader targets will be required. Second, we did not use a crossover study design. We standardised the order of sessions: the control session was always followed by the PMR session because of the potential influence of the PMR session on the control session, were the order to be reversed. In addition, we judged that a design where different subjects performed each condition would be undesirable, due to the potential influence of individual differences. Furthermore, we analysed fMRI data; a more comprehensive analysis including subjective data would be desirable.

CONCLUSIONS

We illustrated the brain activity associated with the performance of PMR. Our study demonstrated less change in brain activity in PMR compared with simple exercise of skeletal muscles; that is, PMR potentially attenuates brain activity. Furthermore, even novices at PMR may be able to induce a cerebral state appropriate for relaxation, concentration, and resistance to local environmental distractions.

Conflicts of interest

We have no conflicts of interest to declare.

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Table 1: Brain regions showing significant activation and deactivation.

Brain region	BA	Side	Cluster size	MNI coordinates			*t* value
				x	y	z	
Control session							
Superior temporal gyrus	22	R	2814	54	−6	0	10.94
Superior temporal gyrus	41	L	1660	−48	−24	8	10.78
Putamen		L	131	−20	0	−2	7.48
Putamen		R	139	18	2	0	7.35
Middle frontal gyrus	6	R	440	14	0	54	7.05
Anterior cingulate cortex	24	R	109	10	20	40	6.23
Insula	13	R	160	34	12	8	5.51
Insula	13	L	78	−32	14	2	5.24
Anterior cingulate cortex	32	L	31	−12	30	18	5.12
Middle frontal gyrus	46	L	46	−32	38	34	4.95
Postcentral gyrus	2	L	10	−62	−32	40	4.90
Parahippocampal gyrus	36	R	9	36	−54	0	−5.09
Middle temporal gyrus	21	L	10	−60	−8	−22	−5.12
Caudate	–	R	20	28	−36	6	−5.36
Caudate	–	R	46	12	18	12	−5.45
Parahippocampal gyrus	36	L	46	−40	−32	−10	−6.83
Parahippocampal gyrus	36	L	80	−36	−40	−6	−7.41
PMR session							
Superior temporal gyrus	22	R	58	66	−14	0	5.63
Superior temporal gyrus	41	L	78	−48	−24	6	5.05
Posterior cingulate cortex	23	L	17	−16	−48	10	−5.19
Inferior frontal gyrus	11	L	7	−26	16	−22	−5.48
Superior frontal gyrus	8	L	30	−22	24	56	−6.05

1 Table 2: Percent signal changes with reference to baseline in different brain regions.

2

	Control session		PMR session	
	Average	SE	Average	SE
Right Superior temporal gyrus	−0.0160	0.0033	−0.0037	0.0017
Left Superior temporal gyrus	−0.0079	0.0024	−0.00501	0.00181
Left Putamen	−0.0036	0.0015	0.0027	0.0012
Right Putamen	−0.0039	0.0011	0.0074	0.0045
Right Middle frontal gyrus	−0.0029	0.0008	−0.0001	0.0009
Right Anterior cingulate cortex	−0.0039	0.0013	0.0012	0.0007
Right Insula	−0.0036	0.0010	0.0023	0.0012
Left Insula	−0.0041	0.0014	0.0004	0.0010
Left Middle frontal gyrus	−0.0054	0.0015	0.0021	0.0009
Left Postcentral gyrus	−0.0071	0.0023	0.0061	0.0031
Right Parahippocampal gyrus	0.0019	0.0009	0.0020	0.0010
Left Middle temporal gyrus	0.0010	0.0019	0.0057	0.0020
Right Caudate	−0.0021	0.0016	−0.0020	0.0015
Left Parahippocampal gyrus	0.0000	0.0013	0.0015	0.0013
Left Posterior cingulate cortex	0.0003	0.0011	0.0061	0.0031
Left Inferior frontal gyrus	−0.0029	0.0030	0.0079	0.0011
Left Superior frontal gyrus	−0.0015	0.0028	−0.0010	0.0028

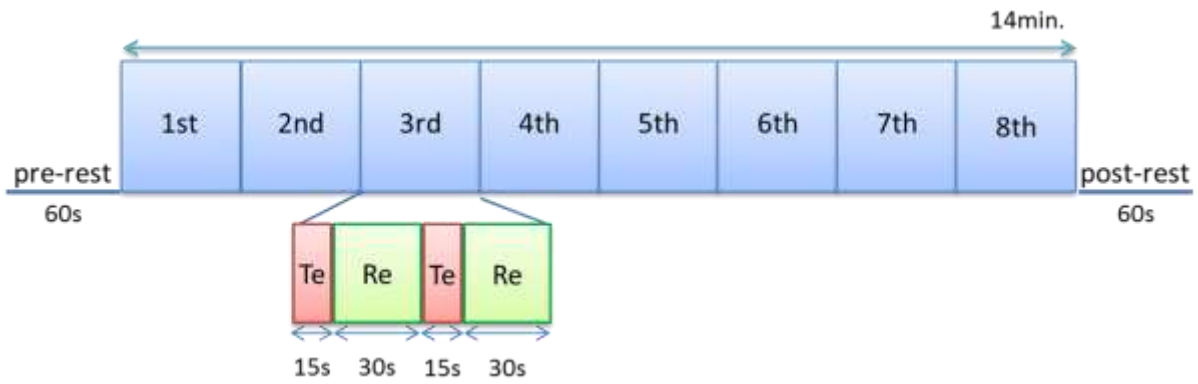

Figure 1. Experimental design. The PMR session and control session used the same design. After a pre-rest time of 60s, there were eight parts. Each part was composed of four blocks: a tensing period (Te) of 15s followed by a relaxation period (Re) of 30s, repeated twice. There was a subsequent 60s post-rest time.

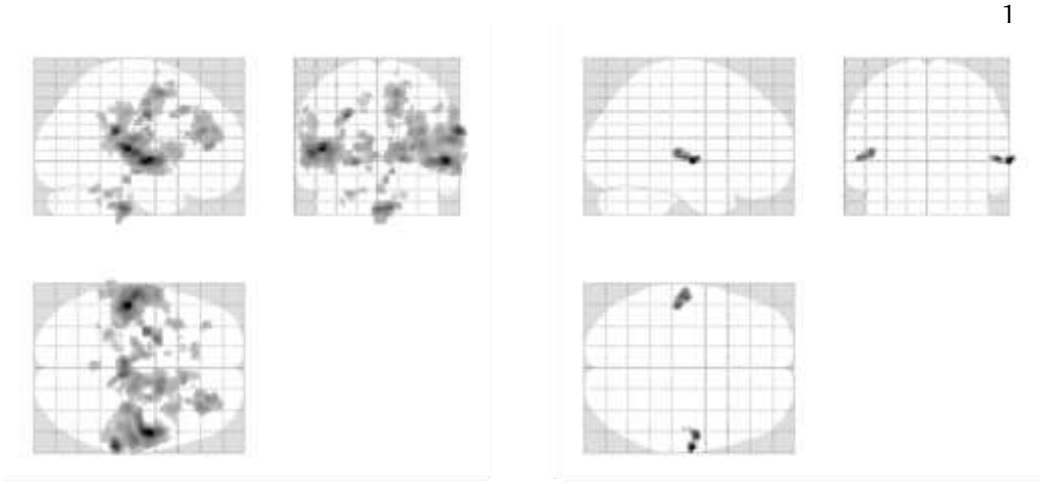

Figure 2. Glass brains in three orthogonal planes, showing maximum intensity projections (MIP). Statistically increased brain activities in control (left image) and the PMR (right image) conditions ($P < 0.001$, uncorrected).

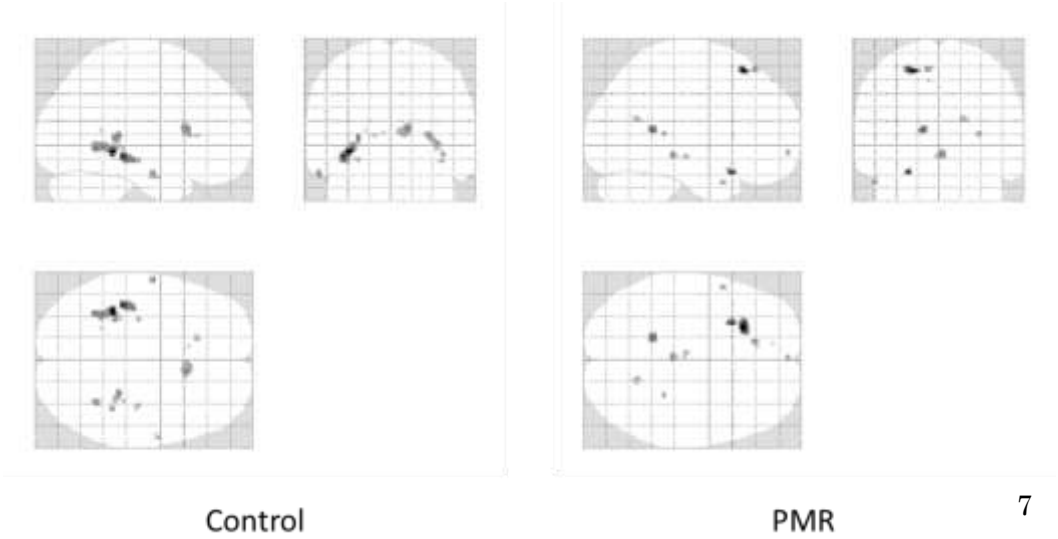

Figure 3. Glass brains in three orthogonal planes showing MIP. Statistically decreased brain activities in the control (left image) and PMR (right image) conditions ($P < 0.001$, uncorrected).

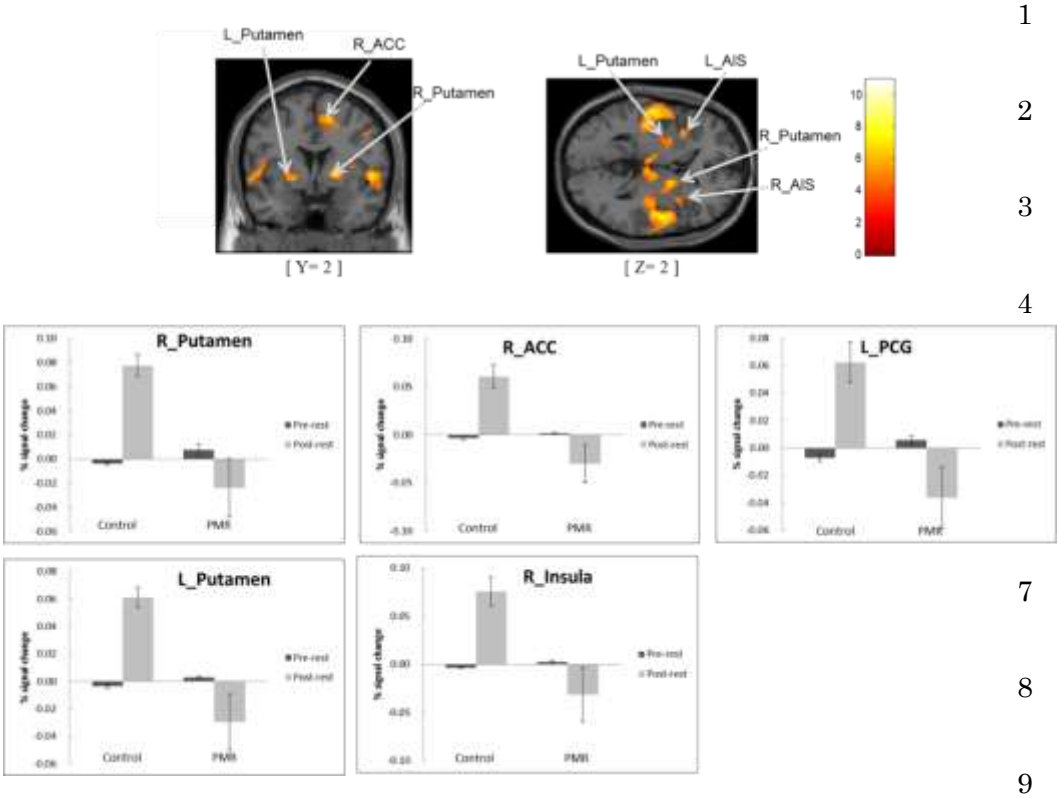

Figure 4. Statistical brain map from results of whole brain analysis for the control session. Mean (±SE) percent signal changes in regions for the session (control, PMR) × time (pre-rest, post-rest) interaction. ACC: Anterior cingulate cortex, PCG: Postcentral gyrus