Hiroshima J. Med. Sci.
Vol. 72, No. 3·4, 33~39, December, 2023
HIMJ 72–6

Effect of fatigue on the brain activity of radiologists while reading images

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ABSTRACT

Reading fatigue in radiologists while assessing diagnostic images reduces their performance and increases errors in image interpretation. Such errors impact patient morbidity and mortality rates as diagnostic imaging plays a crucial role in patient management. We conducted functional magnetic resonance imaging (fMRI) scans of experienced and less-experienced radiologists reading images, both before and after fatigue induction, and assessed their brain activity in both states. Computed tomography (CT) images were presented to seven experienced and six less-experienced radiologists. Pre-fatigue, the radiologists underwent fMRI while reading head CT images; subsequently, they interpreted different CT images for 1 hour outside the MRI suite. Then, in the fatigued state, all 13 radiologists underwent fMRI scanning again while reading a different set of images. During the pre-fatigue reading of head CT images, the bilateral lingual gyri and posterior lobes of the cerebellum were activated in the experienced radiologists but not significantly activated in the less-experienced radiologists. No region was significantly activated in either group of fatigued radiologists. We concluded that the bilateral lingual gyri and posterior lobes of the cerebellum have important roles in image-reading tasks, suggesting the possibility of identifying brain regions involved in specific professional skills. The results indicated that fatigue resulted in reduced brain activation, underscoring the serious effect of excessive work on the brain activation of diagnostic radiologists.

Key words: *Functional MRI, Fatigue, Radiologist, Experienced*

INTRODUCTION

Over the years, the acquisition of diagnostic images has steadily increased[4,10,19], surpassing the growth in radiology staff[6,10]. Consequently, radiologists are under increasing pressure to accurately and swiftly interpret an increasing number of imaging studies. Other studies[9,15,25,26] have found that radiologists often lack energy and motivation, are physically exerted, feel sleepy, and report physical discomfort and oculomotor strain after a long workday. According to Hanna et al.[9], the diagnostic performance of radiologists worsens with increasing fatigue, leading to a 45% increase in viewing times per case, a 60% rise in total gaze fixation, and extended dwell times associated with true- and false-positive decisions. Patel et al.[21] reported that perception errors (i.e., false-negative findings) were associated with faster reading rates and occurred later during the shift. Waite et al.[26] found that errors in diagnostic interpretations increased with increasing demand on radiologists, and Stec et al.[23] reported that fatigue affected the diagnostic accuracy of radiologists.

Fatigue can be classified as physical and/or mental fatigue[25]. However, image-reading tasks can cause various kinds of fatigue, and radiologists often experience ocular fatigue. Fatigue can be assessed objectively or subjectively, and a range of tools have been developed to measure its degree. Examples are the Maintenance of Wakefulness Test, which examines alertness during the day, and the Psychomotor Vigilance Task and Continuous Performance Test, which are tests of sustained attention. Krupinski and Reiner[15] and Waite et al.[26] presented alternative approaches for measuring fatigue that involved monitoring blood pressure, galvanic skin responses, and heart rate. Nihashi et al.[20] used functional near-infrared spectroscopy to monitor fatigue in radiologists during prolonged image interpretation.

Functional magnetic resonance imaging (fMRI), an objective functional neuroimaging tool, has been performed to evaluate changes in brain activity related to physical and mental fatigue caused by fatiguing hand

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exercises, continual visual search tasks, sustained practice with a flight simulator, mental arithmetic, and language tasks, among others[1–3,8,14,24]. Some of the researchers revealed that the idling brain state was related to continual visual search tasks and mental fatigue[8,24]. Other researchers have identified changes in brain activity induced by training and experience. Karni et al. [12,13] observed an increase in cortical activity in the contralateral primary motor cortex due to the practice of rapid finger movement each day for several weeks. Additionally, brain activation during actual and imagined performances was more widely distributed among amateur violinists than in professionals[17]. These results suggest that among professionals, brain activation relating to specific skills is more narrowly distributed and shows higher activity than in non-professionals. Based on the above, there is a possibility that changes in brain activity related to fatigue are different between professionals and non-professionals.

We hypothesized that in radiologists, fatigue induced by prolonged image-reading leads to a reduction in brain activation and that there is a difference between experienced and less-experienced radiologists. This study aimed to use fMRI to compare brain activation in experienced and less-experienced radiologists during image-reading in pre-fatigued and fatigued states.

MATERIALS AND METHODS

Participants

Participants included 13 radiologists. One group (five males, two females; median age 35, range 31–41 years) consisted of seven experienced radiologists, with a median career length of 9 years (range: 6–14 years). Their reading experience covered > 6 years, and all were board-certified specialists. The second group included six age-matched less-experienced radiologists (four males, two females; median age: 33 years, range: 30–42 years). They had read images for a median of 1.3 years (range: 0.2–3.0 years). All 13 radiologists were right-handed, free of neurological disorders, and had normal or corrected-to-normal vision. This study was approved by the Ethics Committee of Hiroshima University, Japan; prior written informed consent was obtained from all participants.

Procedure

In the pre-fatigue state, all participants underwent fMRI while reading anonymized head computed tomography (CT) images. Then, to produce fatigue, the participants interpreted different CT images for 1 hour outside the MRI suite, as typically done in the course of their daily activities. Participants then underwent another fMRI while performing the reading task in a fatigued state. They scored their level of fatigue on the Visual Analog Scale (VAS) before the acquisition of the fMRI scans in the pre-fatigued state and at the end of all experiments. The VAS scores ranged from 0 (no fatigue) to 10 (total exhaustion).

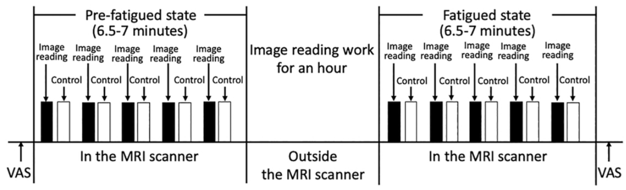

Figure 1 All 13 radiologists underwent fMRI while reading head CT images in the pre-fatigue and fatigued states. All reading tasks involved five reading- and five control blocks. The image-reading and control blocks comprised 5 sets of 23–34 interleaved whole-brain CT images. After reading images in the pre-fatigue state, the radiologists interpreted different CT scans for 1 hour outside the MRI suite. Then, while undergoing fMRI, the radiologists again read different CT images in the fatigued state. All 13 radiologists provided their Visual Analog Scale scores before and after acquisition of fMRI scans. Each reading task lasted 6.5–7 minutes.
fMRI = functional MRI; CT = computed tomography

Experimental task

The radiologists performed novel reading tasks in both the pre-fatigue and fatigued states and were presented with 10 blocks: 5 for image-reading and 5 as the control-block. The reading and control blocks were interleaved and presented five times (Figure 1). For 1 second before presenting the image-reading block, the legend "when you see the lesion, please press the button" appeared at the center of the reading screen. Similarly, the legend "when you see the blackened area, please press the button" appeared when the control-block was presented. Each reading task lasted 6.5–7 min.

Each image-reading block consisted of 23–34 whole-brain CT images that included brain infarcts; on the control-block images, the infarcted area was blackened (Figure 2). To avoid a decrease in brain activation due to the prior experimental reading task, different CT images were presented when the radiologists were in the pre-fatigue and fatigued states. The images were presented at 1.5-sec intervals; the radiologists indicated the recognition of brain infarcts and blackened areas by clicking a button. The image presentation was controlled with presentation software (Neurobehavioral Systems Inc., San Francisco, CA, USA).

Image acquisition

The fMRI scans were acquired on a 3T MRI system (Signa HDxt, GE Healthcare, Milwaukee, WI, USA) using an eight-channel phased-array head coil (USA Instruments, Aurora, OH, USA). During task performance, gradient-echo planar MR images covering the whole-brain were acquired [32 slices, parallel to the anterior–posterior commissure, echo time (TE) = 27 ms, repetition time (TR) = 2500 ms, flip angle = 90°, slice thickness = 4 mm with no gaps, matrix size = 64 × 64, field-of-view (FOV) = 256 × 256 mm, voxel size = 4 × 4 × 4 mm, total scan time = 460 to 570 sec]. Axial 3D fast spoiled gradient-recalled echo images covering the whole-brain were obtained for image registration and normalization (TR/TE = 6.8 ms/1.9 ms, inversion time = 450 ms, matrix = 256 × 256, flip angle = 20°, slice thick-

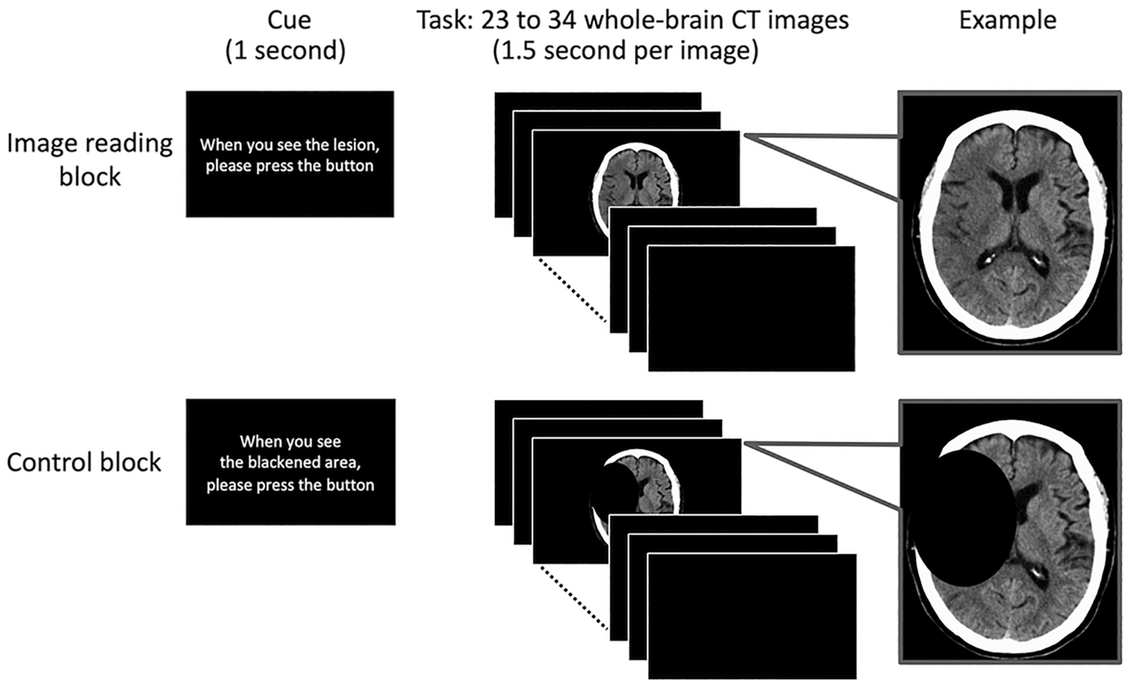

Figure 2 For image-reading blocks, the legend "when you see the lesion, please press the button" was presented on the center of the viewing screen for 1 second. Then, 23–34 whole-brain computed tomography (CT) images that included brain infarcts were shown for 1.5 seconds per image. For the control blocks, the legend "when you see the blackened area, please press the button" was presented at the center of the viewing screen. Then, 23–34 whole-brain CT images that included blackened areas of brain infarcts were presented.

ness = 1 mm, spacing = 0 mm, 180 slices, acquisition time = 359 sec, FOV = 256 × 256 mm).

Image processing and statistical procedures

All fMRI scans were slice-timing corrected, motion corrected, normalized to a standard Montreal Neurological Institute (MNI) template, and spatially smoothed with an 8-mm full-width at half maximum Gaussian kernel using SPM8 (Wellcome Trust Centre for Neuroimaging, London, UK).

To analyze regional activation during the task performance, we applied multiple regression analysis. The regressors included the time course of the image-reading and control blocks and were modeled with a box-car function. The image-reading regressor was contrasted with the control regressor.

The contrast obtained in the pre-fatigue and fatigued states was then subjected to the one-sample *t*-test. Alterations in the pre-fatigue and fatigued states were tested by using the one-sample *t*-test in the experienced and less-experienced radiologists, respectively. Moreover, using the contrast obtained from the image-reading and control blocks, a comparison between the experienced and less-experienced radiologists' regional brain activation was performed using the two-sample *t*-test in the pre-fatigue and fatigued states. Subsequently, we measured the signal intensity of the regions based on the contrast obtained from the image-reading and control blocks and then calculated the average of the right and left regions of all 13 radiologists. Moreover, using the average values, a quantitative comparison between the experienced and less-experienced radiologists' regional brain activation was performed using the two-sample *t*-test in the pre-fatigue state. The experienced and less-experienced radiologists' age and sex were the covariates.

For statistical comparison of the fMRI data, the significance threshold was set at the uncorrected $p < 0.001$ value. The cluster-size threshold was applied for each test, and each cluster-size criterion was calculated with SPM8 at a family-wise error (FWE)-corrected $\alpha < 0.05$.

To examine how fatigue affects activation in different brain regions, we conducted a multiple regression analysis to predict changes in signal intensity in these brain regions based on the change in the VAS scores and the mean-positive predictive value (PPV), which was defined as the ratio of the number of correct button pressings for images showing a brain infarct to the total number of button pressings.

RESULTS

In comparison to the median pre-fatigue VAS scores (experienced group: 4.8; less-experienced group: 4.0), the median scores of the fatigued radiologists were significantly higher (experienced group: 6.9; less-experienced group: 8.1) (Wilcoxon signed-rank test, experienced group: $p = 0.02$; less-experienced group: $p = 0.03$, see Supplemental Figure 1).

In the pre-fatigued state, the mean PPV was 57% in the experienced group and 40% in the less-experienced group. In the fatigued state, the mean PPV was 57% in the experienced group and 46% in the less-experienced group. In the pre-fatigued state, there was a significant

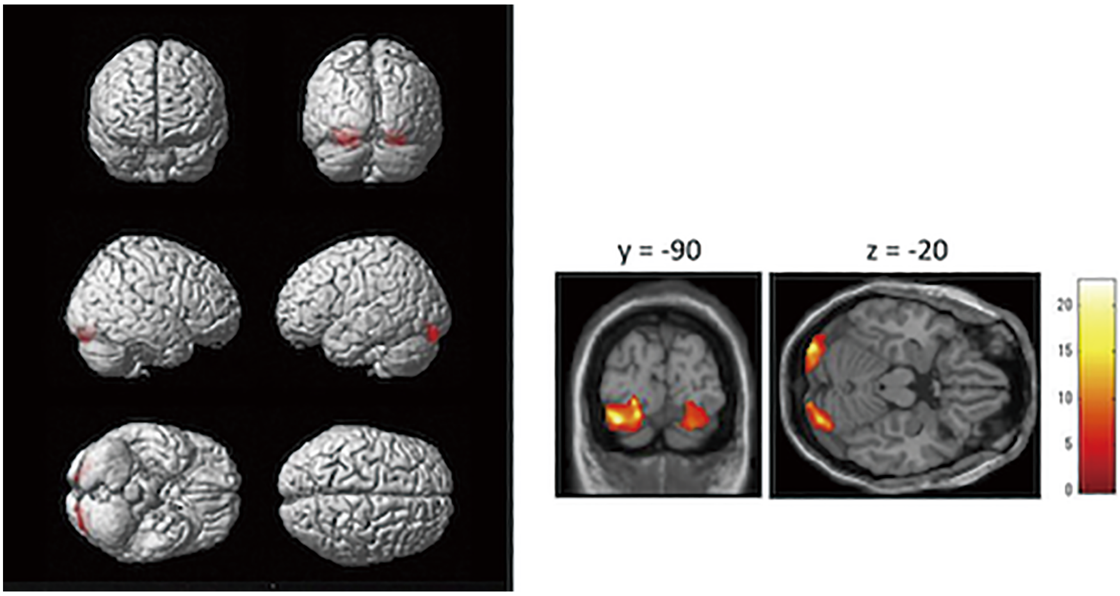

Figure 3 Significantly activated brain regions are projected onto an anatomical image template (uncorrected p < 0.001, extent threshold k = 690 voxels); see Table 1 for details. The color bar shows the t-values from 0 to 23. In the pre-fatigue experienced radiologists, the bilateral lingual gyri (Brodmann area 18) and posterior lobes of the cerebellum were significantly activated.

Table 1 Activated brain regions in experienced radiologists while reading whole-brain head CT images in the pre-fatigue state.

Region of interest	Voxel size	Maximum *t*-score	MNI coordinates of the maximum *t*-score		
			x	y	z
Left lingual gyrus (BA 18)	692	22.74	–30	–90	–20
Left posterior lobes of the cerebellum		18.28	–16	–90	–16
Left posterior lobes of the cerebellum		16.20	–18	–88	–8
Right lingual gyrus (BA 18)	690	14.52	28	–86	–22
Right posterior lobes of the cerebellum		13.72	16	–94	–16
Right posterior lobes of the cerebellum		8.60	32	–74	–4

All maximal t-scores are based on MNI coordinates. The t-scores were obtained from one-sample t-tests.
The voxel clusters that exceeded the statistical threshold [p (uncorrected) < 0.001] and the expected voxels per cluster (≥ 690) encompassed the listed regions.
MNI = Montreal Neurological Institute; BA = Brodmann area; computed tomography (CT)

inter-group difference in the mean PPV (Mann–Whitney U-test, $p = 0.03$). However, the PPV was not significantly different between the pre-fatigue and fatigued states in both the experienced and less-experienced groups (Wilcoxon signed-rank test, experienced group: $p = 1.00$; less-experienced groups: $p = 0.17$, see Supplemental Figure 2).

In the pre-fatigued state, the comparison between image-reading and control tasks showed significant activation of the bilateral lingual gyri [Brodmann area (BA) 18] and the posterior lobes of the cerebellum in experienced radiologists (Figure 3). All clusters exceeding the statistical threshold (uncorrected $p < 0.001$, extent threshold k = 690 voxels) provided by the SPM8 software are listed in Table 1. Pre-fatigue, the one-sample t-test showed that there were no significantly activated regions in the less-experienced radiologists, and no significantly activated regions were observed in either group of fatigued radiologists. Additionally, there were no significantly affected regions in the comparison between the pre-fatigue and fatigued states in either group of radiologists; the two-sample t-test showed that there was no significant difference in brain activation between the experienced and less-experienced radiologists in either state.

The average signal intensity of the activated regions in the pre-fatigue state was not significantly different between the experienced and less-experienced groups (two-sample t-test, $p = 0.08$).

For both the experienced and less-experienced radiologists, neither the change in VAS scores nor the mean PPV served as significant predictors of the change in signal intensity in the bilateral lingual gyri, which showed the highest maximal t-score in the one-sample t-test (see Supplemental Table).

DISCUSSION

We used fMRI to examine the effect of fatigue on brain activation associated with the interpretation of images performed by experienced and less-experienced radiologists.

Pre-fatigue, the bilateral lingual gyri (BA18) and the posterior lobes of the cerebellum showed significant activation in the experienced radiologists. However, there was no significant activation detected in the fatigued state, indicating a reduction in activation in this group. Nevertheless, no specific region displayed significant changes when directly comparing the pre-fatigue and fatigued states. Conversely, in the case of the less-experienced radiologists, we did not observe significantly activated areas in either the pre-fatigue or fatigued states.

Our findings suggest that the bilateral lingual gyri (BA18) and the posterior lobes of the cerebellum have an important role in image-reading. The lingual gyrus is involved in visual processing and encoding of visual memories[5)], while the posterior lobes of the cerebellum are involved in fine motor coordination[22)]. We detected significant activation of these areas in the experienced radiologists performing the reading task in the pre-fatigue state. Our findings are consistent with those of earlier fMRI studies, which reported that activity in brain regions responsible for executing specific skills tends to be higher in professionals in specific areas compared to non-professionals. For instance, a prior study identified specific caudate activation in professional board-game players during the rapid generation of optimal moves[27)]. The caudate nucleus is thought to be responsible for habit formation and execution, so caudate activation might be important for generating optimal moves, which is similar to a habit in that it is quick and implicit. Lotze et al.[17)] found that professional violinists exhibited higher activity in the right primary auditory cortex when performing compared to amateurs. They also noted that professional violinists recruited very few cerebral areas during their performances.

Our results also showed that in both the pre-fatigue and fatigued states, no brain areas were significantly activated in the less-experienced radiologists. Both our own findings, and the findings of previous studies suggest that, irrespective of the profession, less-skilled individuals lack efficiency for recruiting brain areas involved in skill execution. Our study revealed that when the experienced radiologists were in a fatigued state, their brain areas showed reduced activation during image-reading. This finding is consistent with a finding in an earlier fMRI study by Benwell et al.[3)] which reported a reduction relative to the baseline in activation of the primary sensorimotor cortex, supplementary motor area, cerebellum, and primary visual cortex after the study subjects performed handgrip exercises. This deactivation pattern is associated with the negative feedback homeostasis system related to fatigue, as the system seeks to safeguard the body and brain from damage due to overloading[7)].

Batouli et al.[1)] found that mental fatigue in individuals performing face- and word-encoding tasks led to increased activity in the bilateral thalamus, caudate, posterior cingulate, and medial temporal lobe, and in subjects performing face-encoding tasks, activity in the left lingual, precuneus, and posterior cingulate gyri was reduced. Nakagawa et al.[18)] reported that during the performance of attention tasks comprising visual and auditory components, midbrain deactivation related to fatigue was stronger under high- compared to low-attention load conditions. This phenomenon may reflect the suppression of the negative feedback system. These earlier studies suggest that fatigue has broad effects on different brain areas involved in specific tasks.

The fMRI scans obtained in all 13 of our fatigued radiologists revealed no brain area with significantly increased activity. Due to a lack of statistical power, however, we may have missed increased activation; we only studied 13 participants, whereas an earlier investigation studied 57 subjects[1)]. The fMRI studies performed by Esposito et al.[8)] revealed that the signal intensity of a compact cluster located in the left lingual gyrus was increased in mentally exhausted subjects; however, unlike our scans, their scans were obtained in an at-rest state. We could not show differences in brain activation between the experienced and less-experienced radiologists in either the pre-fatigue or fatigued states. It is possible that the relatively small number of participants has led to these non-significant results.

When our subjects were fatigued, after having interpreted images for 1 hour before re-scanning, brain activation on their fMRI scans was reduced. This result suggests that the daily professional activities of even experienced diagnostic radiologists elicit a reduction in their brain activation.

The changes in the VAS scores were not significantly correlated with changes in the signal intensity of brain areas involved in image-reading. Ishii et al.[11)] provided evidence for the unconscious regulation of task performance in the fatigued state. They demonstrated that fatigue can be learned unconsciously and suggested the presence of a mechanism that led to a decrease in task performance without the task performer being aware of the sensation of fatigue. The fact that fatigue was not induced and that there were individual differences in fatigue tendencies may make our results non-significant.

According to Krupinski et al.[16)], although accurate interpretation of images showing obvious injuries was not affected by fatigue, the detection of subtle fractures was affected. We found that fatigue in the experienced and less-experienced radiologists had no significant effect on the PPV, possibly because we did not consider the effect of lesion visibility on the presented head CT scans in our evaluation of the fMRI scans and/or because the imposed 1-hour reading of images outside the MRI suite was insufficient to elicit statistically significant effects on the PPV.

This study had several limitations. First, due to the relatively small number of radiologists, our findings are exploratory, and we could not entirely avoid type II errors or account for individual differences. To achieve highly reliable findings, it is essential to investigate the impact of fatigue on the correct interpretation of images by radiologists in larger study populations. Second, the laboratory setting of our experiments may have affected the radiologists' image reviews. As they only interpreted head CT images, the effect of fatigue on their brain activity during their routine clinical image reviews might differ. Thirdly, it's possible that habituation to the reading task influenced brain activity because the changes in the VAS scores did not show a significant correlation with changes in the signal intensity of brain areas involved in image interpretation.

CONCLUSION

Our results showed significant activation in the bilateral lingual gyri and posterior lobes of the cerebellum in experienced radiologists performing image interpretation in a pre-fatigue state. However, when these experienced radiologists interpreted images in a fatigued state, no significant activation was detected. No significant activation was found when the less-experienced radiologists read images, whether in a pre-fatigue state or a fatigued state. Our fMRI study may contribute to a better understanding of brain activity in fatigued subjects as well as to the development of preventive measures against fatigue in diagnostic radiologists performing their daily reading tasks.

ACKNOWLEDGEMENTS

We thank Dr. Tomoyuki Akita for assistance with data analysis, Enago (www.enago.jp) and Ursula Petralia for the English language review.

(Received September 5, 2022)
(Accepted May 8, 2023)

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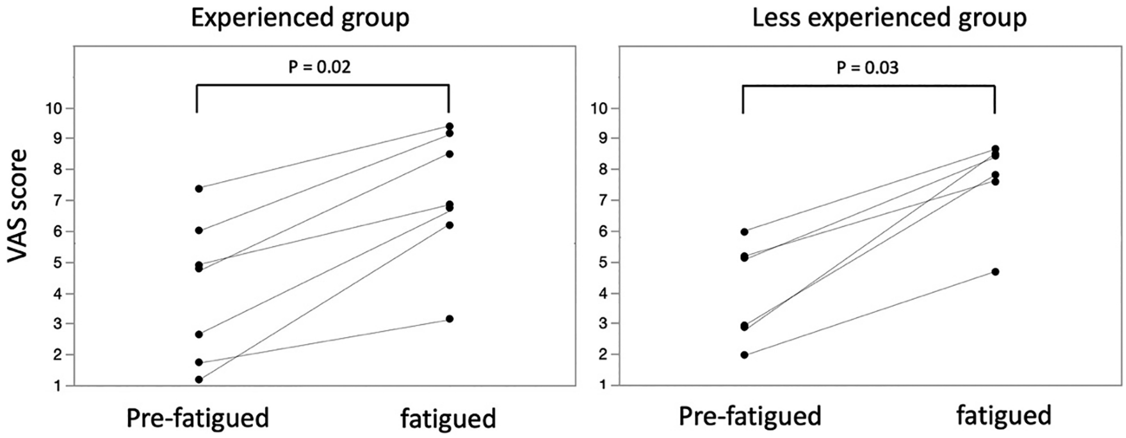
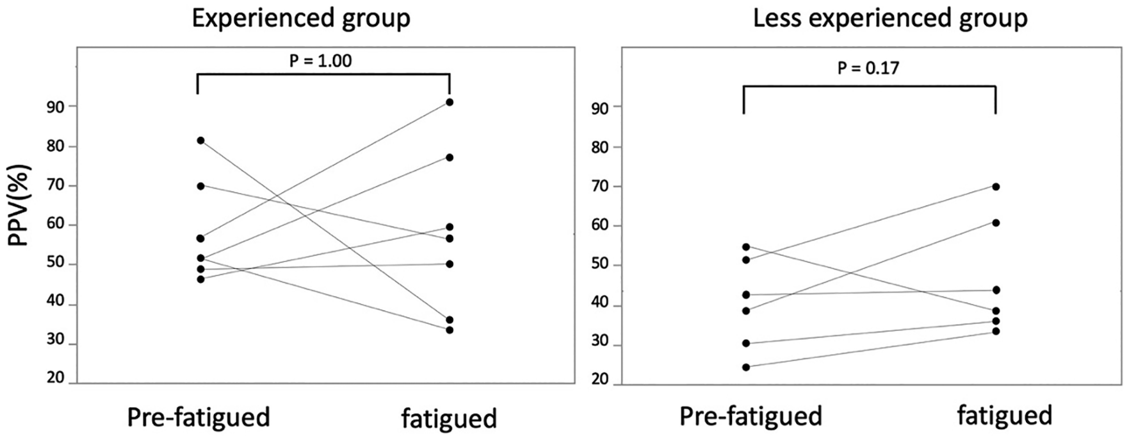
SUPPLEMENTARY MATERIALS



Supplemental Figure 1 Visual Analog Scale (VAS) scores were recorded in the pre-fatigue and fatigued states. In both the experienced and less-experienced radiologists, the median score was significantly higher in the fatigued state than in the pre-fatigue state (Wilcoxon signed-rank test).



Supplemental Figure 2 The positive predictive value (PPV) was recorded in the pre-fatigue and fatigued state. There was no significant difference between the PPVs (Wilcoxon signed-rank test).

Supplemental Table. Multiple regression analysis to examine the effect of fatigue on brain activation.

	Experienced group				Less-experienced group			
	Left lingual gyrus		Right lingual gyrus		Left lingual gyrus		Right lingual gyrus	
	β	p	β	p	β	p	β	p
PPV	–0.22	0.75	0.03	0.96	0.1	0.95	–0.46	0.71
VAS	–0.64	0.66	–0.65	0.63	0.46	0.8	–0.12	0.93

Shown is the correlation between the change in the VAS scores and mean PPV and the change in the signal intensity in the bilateral lingual gyri showing the highest maximal *t*-score in the one-sample *t*-test.
VAS = Visual Analog Scale
PPV = positive predictive value
β = standardized partial regression coefficient