



Monitoring of fatigue in radiologists during prolonged image interpretation using fNIRS

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Abstract

Purpose To determine whether functional near-infrared spectroscopy (fNIRS) allows monitoring fatigue in radiologists during prolonged image interpretation.

Materials and methods Nine radiologists participated as subjects in the present study and continuously interpreted medical images and generated reports for cases for more than 4 h under real clinical work conditions. We measured changes in oxygenated hemoglobin concentrations [oxy-Hb] in the prefrontal cortex using 16-channel fNIRS (OEG16ME, Spectratech) every hour during the Stroop task to evaluate fatigue of radiologists and recorded fatigue scale (FS) as a behavior data.

Results Two subjects showed a subjective feeling of fatigue and an apparent decrease in brain activity after 4 h, so the experiment was completed in 4 h. The remaining seven subjects continued the experiment up to 5 h. FS decreased with time, and a significant reduction was observed between before and the end of image interpretation. Seven out of nine subjects showed a minimum [oxy-Hb] change at the end of prolonged image interpretation. The mean change of [oxy-Hb] at the end of all nine subjects was significantly less than the maximum during image interpretation.

Conclusion fNIRS using the change of [oxy-Hb] may be useful for monitoring fatigue in radiologists during image interpretation.

Keywords Radiologists · Workload · Fatigue · Spectroscopy · Near-infrared

Introduction

The workload of radiologists continues to increase worldwide with the development of diagnostic imaging technologies, and prolonged image interpretation is often required in daily clinical practice [1, 2]. The disparity between workload demands and the number of radiologists available is becoming more apparent each year.

It is important and essential for radiologists to maintain attention and performance for accurate image interpretation in daily clinical practice.

Fatigue due to a prolonged workload often results in misdiagnoses, which are disadvantageous for patients and may lead to medical malpractice. Fatigue in radiologists has been extensively examined. Krupinski et al. reported that after 1 day of clinical reading, radiologists exhibited a reduced ability to focus on displayed images, more prominent symptoms of fatigue and oculomotor strain, and reduced detection accuracy [3].

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Waite et al. reviewed errors in diagnostic interpretations, which are a common occurrence exacerbated by the increasing demands on radiologists [4].

A systemic review of fatigue in radiologists was recently conducted and the findings obtained indicated that fatigue is present and affects diagnostic accuracy [5].

Continuous long cognitive workloads lead to reduction of behavioral performance, which cause mistakes and increase fatigue feelings. This is known as “a vigilance decrement” or “time-on-task (TOT) effects [6–8].

Taylor-Phillips et al. conducted a retrospective review on the vigilance decrement in radiologists, and reported a sensitivity decrease or specificity increase over the course of reading 100 chest X-rays, 60 bone fracture X-rays, and 100 chest CT scans [9].

Recent technological advances in neuroimaging have enabled the mechanisms of human brain functions to be investigated using non-invasive methods. The relationship between subjective fatigue and brain function has been assessed using functional near-infrared spectroscopy (fNIRS), electroencephalography (EEG), PET, MEG, and fMRI [8, 10–14]. A neuroimaging analysis focusing on the relationship between long-term work and fatigue has also been conducted [8, 15].

fNIRS enables the non-invasive detection of brain function near the brain surface using near-infrared light and monitors changes in oxygenated hemoglobin ([oxy-Hb]) and deoxygenated hemoglobin ([deoxy-Hb]) in micro-blood vessels on the brain surface [16–18].

The advantage of NIRS is that it provides direct, real-time measures of changes in [oxy-Hb] and [deoxy-Hb] with acceptable spatial resolution. One of its main advantages is that measurements of brain activity are possible at the bedside or during desk work, and not in a laboratory. Therefore,

fNIRS is expanding in the field of neuroscience and psychiatry [19–22].

Difficulties are associated with the objective assessment of fatigue, because the neuropsychological scale is a subjective evaluation and the degree of fatigue varies depending on the condition of the subject.

Fatigue needs to be objectively evaluated in radiologists to monitor optimal conditions for image interpretation and ensure a reasonable workload, thereby maintaining the quality and safety of clinical practices.

To the best of our knowledge, however, it has not been investigated to objectively evaluate fatigue in radiologists during medical image interpretation using fNIRS. The purpose of the present study was to determine whether fNIRS allows monitoring fatigue in radiologists during image interpretation.

Materials and methods

Subjects

This study was approved by the Institutional Review Board of Komaki City Hospital and Nagoya Jhohoku Radiology Clinic.

A comprehensive explanation of the experiment was given to subjects before this study and written informed consent was obtained.

One female and eight male board-certified diagnostic radiologists participated in the present study, and work full time (Table 1). All subjects were right-handed and had no medical issues. We confirmed that there were no color blind radiologists.

Table 1 Summary of experience and working style of subjects

Subject	Speciality	Experience (year)	Working time	Work on holiday	Others
1	Diagnostic radiology	30>	Full	Sometimes	
2	Diagnostic radiology	15>	Full	None	
3	Diagnostic radiology	30>	Full	None	
4	Diagnostic radiology	15>	Full	Sometimes	
5	Diagnostic radiology	20>	Full	Saturday morning	
6	Diagnostic radiology	30>	Full	None	Coffee (before experiment)
7	Diagnostic radiology	15>	Full	Sometimes	
8	Diagnostic radiology	15>	Full	Saturday morning	
9	Diagnostic radiology	20>	Full	Saturday morning	Coffee (between work)

Radiological experience of image interpretation was more than 15 years in all subjects (more than 30 years in subject 1, 3, 6, more than 20 years in subject 5, 9, and more than 15 years in subject 2, 4, 7, 8)

Three radiologists have work on Saturday morning (subject 5, 8, 9) as routine. In addition, three have occasional work (subject 1, 4, 7) and 3 are off (subject 2, 3, 6) on Saturdays

Two subjects take coffee in the present study

Radiological experience of image interpretation was more than 15 years in all subjects, with two having more than 30 years' experience.

Procedure of the study

Nine subjects interpreted computed tomography (CT) (mainly whole-body imaging) and/or magnetic resonance imaging (MRI) (mainly neuroimaging or orthopedic imaging) at the Nagoya Johohoku Radiology Clinic and actually generated reports for clinical cases for more than 4 h in a

real clinical routine with an approximately 10-min interval every hour for a fatigue assessment (Fig. 1a).

The monitoring of fatigue, consisting of fNIRS measurements and a fatigue questionnaire before and during the experiment, was performed on subjects every hour.

The experiment was conducted from Saturday afternoon to evening. None of the subjects had any health issues prior to the initiation of the experiment.

Subjects were allowed to drink beverages during image interpretation similar to daily work conditions.

If subjects were subjectively fatigued or exhibited decreases in brain activity after 4 h, the experiment was

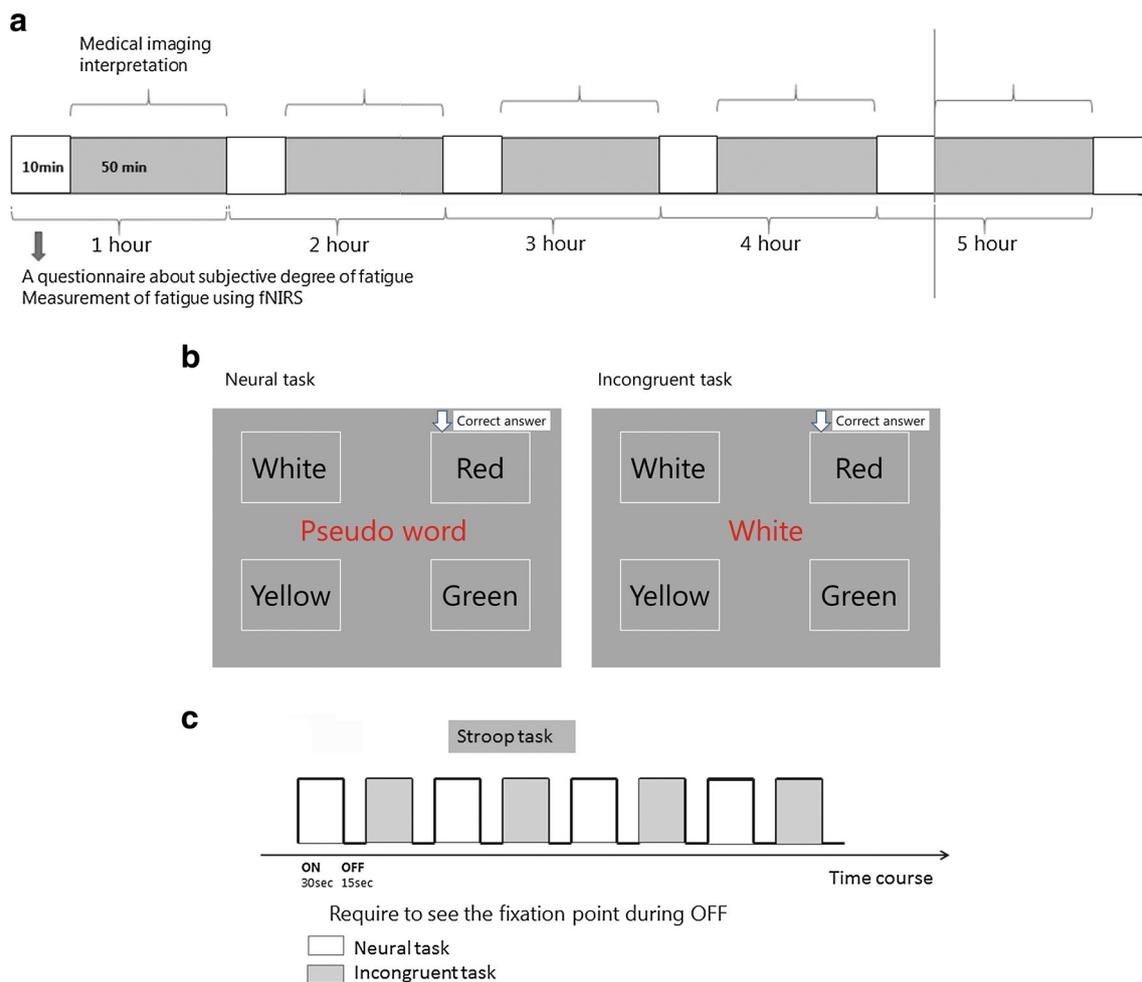


Fig. 1 **a** Procedure of the experiment. There were more than four medical imaging interpretation sessions (horizontal line) and up to five sessions. In the first rest period, a questionnaire on the subjective degree of fatigue and measurement of fatigue using fNIRS were performed. **b** In the neural task, the stimulus pseudoword was in red font, the subjects had to choose the corner word “Red” displayed on left upper corner. In the incongruent task, the stimulus word was the name of a color displayed in an incongruent font color, such as “white” displayed in Red font, the subjects had to choose the corner word “Red” displayed on left upper corner. **c** Monitoring of brain

activity using the Stroop task. We measured [oxy-Hb] changes in the prefrontal cortex by 16-channel fNIRS (OEG16ME, Spectratech, Tokyo, Japan) during the Stroop task every hour, which is used as a parameter for physiological changes related to fatigue. A block design was applied with eight sets of ON/OFF. Regarding brain functional imaging, the Stroop task (30 s) was alternated with a rest condition (15 s) during the fNIRS measurement. Neural and incongruent tasks were alternately presented. Under rest conditions, each subject was asked to watch a fixation point and concentrate on the present task (color figure online)

completed in 4 hr. If subjects had the capacity to continue, another hour of image interpretation was performed, resulting in 5 h of continuous work.

Decisions regarding whether to continue the experiment were judged comprehensively, together with the degree of subjective fatigue and the visual deterioration of fNIRS data by T.N.

Each subject was informed in advance that the experiment was up to 5 h.

Fatigue assessment

An original questionnaire on the subjective degree of fatigue was given to each subject to obtain behavioral data. Based on this questionnaire, a 5-point assessment was applied and defined as the fatigue scale (FS): 5, very well; 4, well; 3, normal; 2, slightly tired; and 1, very tired.

Stimuli and experimental procedure

We employed the Stroop task to monitor executive and cognitive functions considered to indicate mental fatigue in subjects. Four words (white, yellow, green, and red) were displayed on each corner of the monitor, and a stimulus word in Japanese was simultaneously presented in the center. We asked each subject to select the correct word as quickly as possible with a mouse click.

In the neutral task, the stimulus word was a pseudoword that matched the font color of each corner word and the pseudoword was an enumeration of characters, which itself had no meaning. For example, if the stimulus pseudoword was in red font, the participants had to choose the corner word “red”. On the other hand, in the incongruent task, the stimulus word was the name of a color displayed in an incongruent font color, such as “white” displayed in red font [23]. Figure 1b shows the representative neural and incongruent task. A block design was applied with eight sets of stimulus and rest conditions. Regarding brain functional imaging, the Stroop task (30 s) was alternated with a rest condition (15 s) during fNIRS measurements. Under the rest condition, subjects were asked to gaze at the fixation point in the center of the monitor and to clear their mind (Fig. 1c).

fNIRS recording and analysis

NIRS system

We measured changes in [oxy-Hb] in the prefrontal cortex every hour using 16-channel fNIRS (OEG16ME, Spectrat-ech, Japan) during the Stroop task, which is used as a parameter for physiological changes related to fatigue.

The OEG-16 NIRS system consisted of six emission and six detection probes, which enabled measurements from

sixteen channels and provided three parameters: changes in [oxy-Hb] and [deoxy-Hb] and total [total-Hb] changes. The temporal resolution of acquisition was 0.08192 s.

We examined changes in [oxy-Hb] in this analysis, because it is the most sensitive to neural activity [24–26]. Regarding the setting of the NIRS system, the center of the NIRS probe was placed on Fpz according to the International 10/20 System (18, 20). Every time, a well-trained experimenter (T.N.) set the probe in the same position carefully.

Raw NIRS records were passed through a bandpass filter (0.01–0.1 Hz) using fast Fourier transform to reject records with movement artifacts [23, 27].

A 3D topographic map of [oxy-Hb] changes in representative subjects was created using the virtual registration method (Brain View, B. R. Systems, Japan).

Data preprocessing

Integral values were calculated with positive changes throughout all task periods and showed the size of the hemodynamic response during the 30-s activation task periods (Fig. 2a) [28]. We classified data from the 16 channels into defined integrated areas to evaluate the location of the brain response. The total analysis integrated all channels: medial consisted of Ch5–12, lateral of Ch1–4 and Ch13–16, the right side of Ch1–7, and left side of Ch10–16 (Fig. 2b).

Analysis of fNIRS data

We initially compared the effects of neural and incongruent tasks.

We then analyzed changes with time in the median reaction time, accuracy, and fNIRS data in each task. fNIRS data were analyzed separately for the neural and incongruent tasks.

Schroeter et al. reported that the hemodynamic response was stronger during incongruent than neutral trials of the Stroop task in the lateral prefrontal cortex bilaterally due to interference, which was interpreted as a stronger brain activation during incongruent trials of the Stroop task, due to interference [18]. We considered that the incongruent task is more affected to fatigue than neural task, and in the present study, the change in [oxy-Hb] in the incongruent task was mainly analyzed.

To investigate whether the change in [oxy-Hb] was reduced at the end of the experiment, we added a comparison of the maximum value over time with the value at the end.

We then investigated the relationship between behavioral data and fNIRS data. The relationship between the percentage change from the first to last time in FS and total [oxy-Hb] change was calculated according to the following

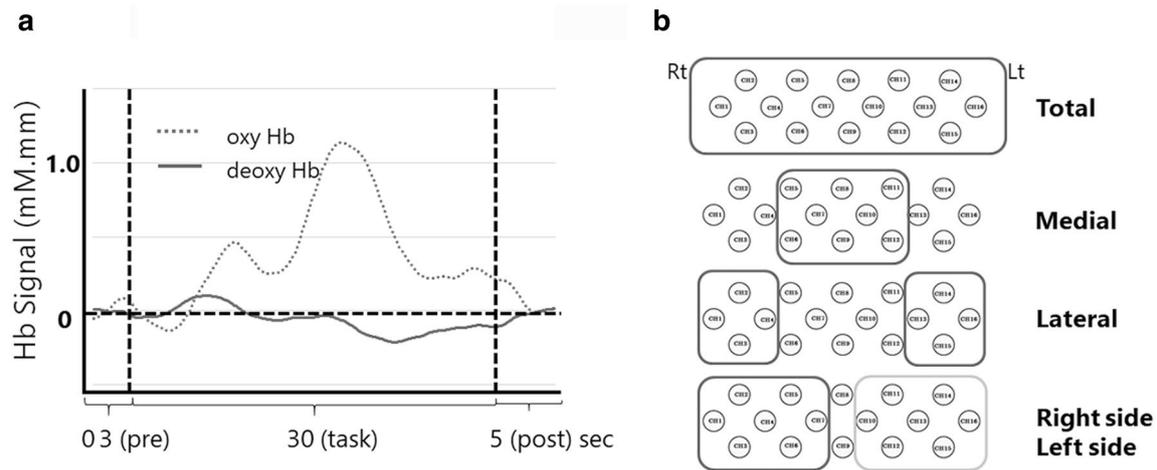


Fig. 2 a Typical time-course pattern of fNIRS signals with the Stroop task. An integral value was calculated with a positive change throughout all task periods and showed the size of the hemodynamic response during the 30-s activation task period. Oxy-Hb oxygenated hemoglobin signal (dotted line), deoxy-Hb deoxygenated hemoglobin signal (solid line). The integral value was calculated. The area sur-

rounded by oxy-Hb and the X axis was integrated for 30 s during the Stroop task. **b** Channel setting and evaluation areas. We classified 16-channel data into defined integrated areas to evaluate the location of the brain response. The total analysis integrated all channels: medial consisted of Ch5–12, lateral of Ch1–4 and Ch13–16, the right side of Ch1–7, and left side of Ch10–16

formula: $\text{ratio} = (\text{Last} - \text{First}) / \text{First} (\%)$, and the relationship between FS and total [oxy-Hb] was also investigated.

Statistical analysis

A repeated-measures ANOVA was performed to compare the effects of neural and incongruent stimuli. A one-way ANOVA with multiple comparisons and the Bonferroni correction were performed to compare the time course of behavioral data and the average integral values of [oxy-Hb] changes obtained in neural and incongruent tasks, respectively.

The paired *t* test was performed to compare the maximum value over time with the value at the end. Pearson's correlation analysis was conducted to evaluate the relationships between the average integral values of [oxy-Hb] and FS.

Statistical analyses were performed using Stata 13 software (Stata Corp, USA). Significance was defined as $P < 0.05$.

Results

Two subjects showed a subjective feeling of fatigue and an apparent decrease in brain activity after 4 h, so the experiment was completed in 4 h. The remaining seven subjects continued the experiment up to 5 h.

Behavioral results

The mean FS, median reaction time, and accuracy data are shown in Table 2. The mean FS decreased with time (Fig. 3a). A significant difference was observed in the mean FS for each hour [$F(5, 98) = 2.43, P = 0.04$], and a post hoc analysis with the Bonferroni correction showed a significant reduction between before and after 5 h of image interpretation.

A decrease was observed in FS in most subjects as the experiment progressed, whereas an increase was only noted in subject 8.

The median reaction time decreased with time in the neural and incongruent tasks. Time course patterns were similar, and no significant differences were observed between these two tasks (Fig. 3b). No significant differences were noted in time courses both in the neural and incongruent tasks.

Mean accuracy decreased once after 3 h, but then reached the same level as that in the first half of both the neural and incongruent tasks. Time course patterns of mean accuracy were similar, and no significant differences were observed between these two tasks (Fig. 3c). No significant differences were noted in time courses both in the neural and incongruent tasks.

fNIRS results

Time course of fNIRS data

Table 2 shows the mean integral values of [oxy-Hb] changes at each location (Total, Medial, Lateral, rt. side, and Lt. side).

Table 2 Summary of behavior and fNIRS data

H	Task	Fatigue scale	Accuracy	Median RT	Total	Medial	Lateral	rt. side	lt. side
0	Neural	3.22±0.81	99.4±0.9	1.20±0.23	16.5±15.0	9.5±7.0	7.0±10.3	6.2±9.1	6.8±6.4
1	Neural	2.78±0.65	99.0±1.2	1.17±0.21	9.1±25.4	4.4±14.5	4.7±12.3	3.6±11.2	4.0±11.1
2	Neural	2.78±0.94	99.0±1.3	1.11±0.19	10.1±16.6	4.4±8.8	5.7±8.1	4.9±8.3	4.1±8.0
3	Neural	2.78±0.81	97.1±5.5	1.12±0.24	10.9±13.9	5.9±8.3	5.0±7.2	4.8±7.2	4.3±5.2
4	Neural	2.44±1.29	99.2±1.1	1.11±0.20	12.5±20.0	6.9±10.5	5.6±10.5	5.5±11.7	4.4±6.5
5	Neural	2.14±1.03	98.4±1.3	1.10±0.22	19.7±15.2	13.3±8.9	6.4±8.7	7.2±10.3	8.4±4.5
0	Incongruent	–	98.8±1.6	1.19±0.20	20.7±13.3	10.8±6.5	9.8±9.8	9.1±8.9	7.6±5.4
1	Incongruent	–	98.1±2.0	1.19±0.21	19.4±19.0	11.3±12.2	8.1±8.3	9.0±10.1	7.5±7.7
2	Incongruent	–	97.1±3.7	1.12±0.21	22.8±18.2	12.0±9.8	10.7±8.7	8.9±10.5	10.7±7.4
3	Incongruent	–	96.7±3.9	1.13±0.23	23.7±8.2	11.5±5.8	12.3±4.3	11.3±3.5	9.4±4.5
4	Incongruent	–	98.8±1.1	1.12±0.18	13.4±17.0	8.7±10.5	4.7±8.2	5.2±7.7	4.9±6.5
5	Incongruent	–	98.6±1.1	1.12±0.25	13.9±22.5	9.1±10.3	4.8±13.5	4.9±14.1	5.8±8.3

Mean values ± S.D. are presented for each parameter. rt. is right. lt. is left. RT is the reaction time. In the fatigue scale, the same values were observed in the neural and incongruent tasks. An integral value was calculated with a positive change throughout all task periods and showed the size of the hemodynamic response during the 30-s activation task period

Total (total analysis integrating all channels), Medial (medial consisting of Ch5–12), Lateral (lateral of Ch1–4 and Ch13–16), rt. side (the right side of Ch1–7), and lt. side (left side of Ch10–16)

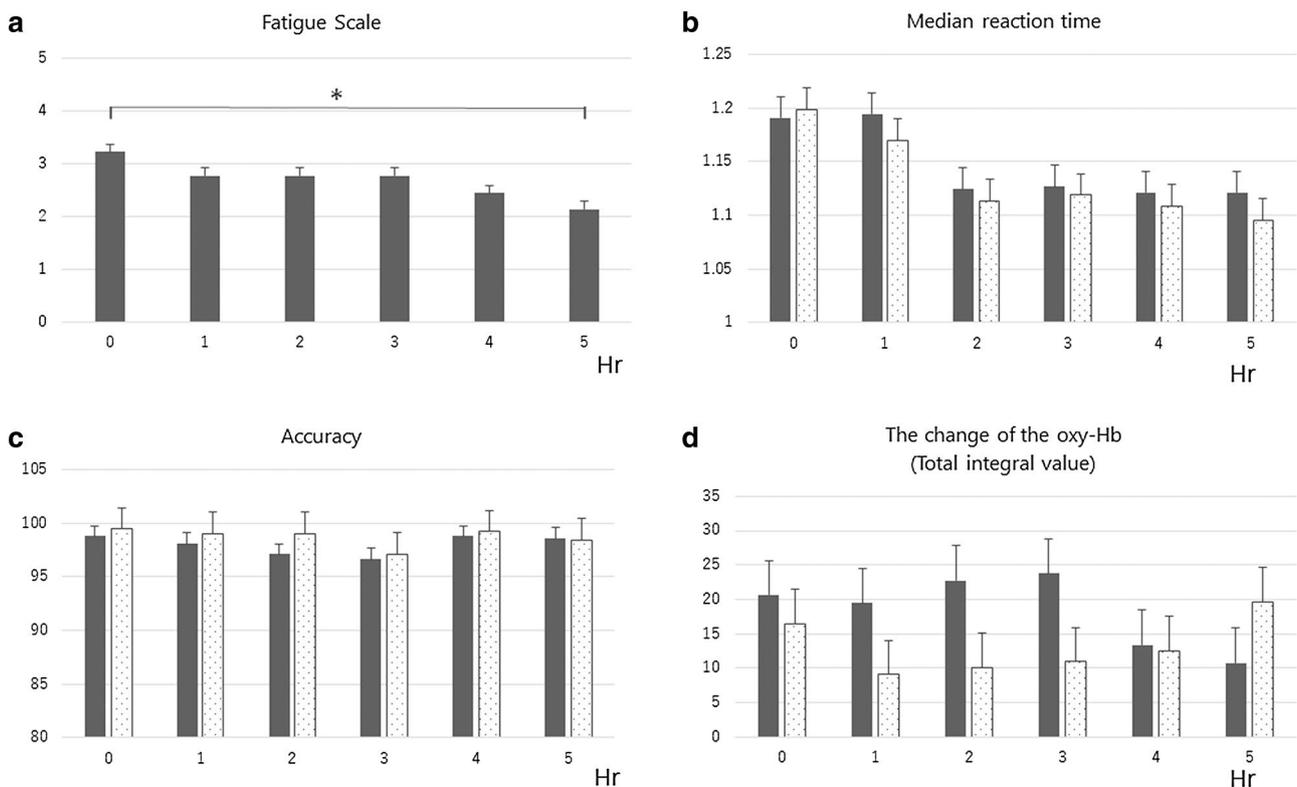


Fig. 3 **a** Time course of changes in the fatigue scale. A significant difference was observed between 0 and 5 h ($P < 0.05$). **b** Time course of changes in median reaction times under neural (dot bar) and incongruent conditions (gray bar). No significant differences were observed between the neural and incongruent tasks. The scale of the Y axis is sec. Error bars represents standard errors. **c** Time course of changes in mean accuracy times under neural (dot bar) and incongruent conditions (gray bar). No significant differences were observed

between the neural and incongruent tasks. The scale of the Y axis is percentage accuracy. Error bars represents standard errors. **d** Time course of changes in mean total integral values of [oxy-Hb] under neural (dot bar) and incongruent conditions (gray bar). No significant differences were observed between the neural and incongruent tasks. The scale of the Y-axis is mM mm s. Error bars represent standard errors

Figure 3d shows the mean total integral values of [oxy-Hb] changes in the neural and incongruent tasks. Although time-course patterns were not similar, no significant differences were noted between these two tasks. The mean total integral values of [oxy-Hb] in the neural task appeared to decrease in the middle stage of the experiment and increase in the last stage of the experiment; however, no significant differences were observed in the time course.

The mean total integral values of [oxy-Hb] in the incongruent task appeared to decrease in the last stage of experiment, namely, after 4 and 5 h; however, no significant differences were observed in the time course.

Figure 4a shows the time course of the mean total integral values of [oxy-Hb] changes in the incongruent task in all nine subjects; only subjects 6 and 8 showed an increase in the mean total integral values of [oxy-Hb] at the end of the task, while the other seven subjects showed a decrease at the end and these values were the minimum observed during this procedure. Figure 4b shows 3-D topographic map of maximum and minimum [oxy-Hb] changes using the virtual registration method in nine subjects.

The change in [oxy-Hb] at the end of the experiment is visually less than that at the peak in seven subjects excluding subjects 6 and 8.

Comparison of maximum values and end times

Seven subjects showed minimum values at the end of the experiment, excluding subjects 6 and 8. Regarding maximum values, an inter-individual difference was observed. Three subjects showed maximum values after 3 h, 2 after 3 h, and 1 before image interpretation and after 4 h (Fig. 4a).

A comparison of the integral values of [oxy-Hb] changes was performed between maximum values and end times (Fig. 5a). The [oxy-Hb] changes at the end significantly decreased compared with that of maximum values with the paired *t* test and a significant difference was noted ($P=0.0008$).

Localization of brain responses

An analysis was performed based on several defined areas to evaluate the location of the brain response; however, no significant differences were observed in brain activity due to localization.

Correlation

Time courses (h) and FS negatively correlated ($P<0.01$), while median reaction times and accuracy positively correlated ($P<0.05$).

A correlation was not observed between the percentage change from the first to last time in FS and the total [oxy-Hb]

change ($r=0.48$) (Fig. 5b); however, a positive association was noted. Percentage changes in FS from the first to last time [ratio = (Last – First)/First %] ranged between –0.67 and 0.33%.

Percentage changes in total [oxy-Hb] from the first to last time [ratio = (Last – First)/First %] ranged between –5.61 and 1.78%.

Representative waveforms of subjects 1 and 3

As shown in Fig. 6, the integral value of the [oxy-Hb] change in subject 1 peaked after 3 h and then reached its minimum after 4 h. The FS of subject 1 was 1 (very tired) at the end. The integral value of the [oxy-Hb] change in subject 3 peaked after 2 h and then reached its minimum after 4 h. The FS of subject 3 was 2 (tired) at the end.

Discussion

In the present study, we used fNIRS to measure the brain activity of diagnostic radiologists during daily clinical practices. The time course of changes in [oxy-Hb] was easily obtained from each radiologist in a short time.

The results of the present study showed that brain activity in the Stroop task with incongruent stimulus was decreased by 4–5 h of continuous image interpretation, namely, the execution or cognitive function of subjects decreased. These results suggest that radiologists need to take a rest interval and attempt to restore brain activity before reductions occur in execution or cognitive function.

The Stroop task has been used as an indicator of execution or cognitive function in many studies [14, 20, 26, 29, 30]. Ochi et al. examined changes in [oxy-Hb] to evaluate neural activity related to the Stroop task, assessed cortical activation patterns during the color-word Stroop task before and after 10 min of moderate-intensity exercise or rest under hypoxic conditions, and demonstrated a decrease in executive function and reduction in the activation of the left dorsolateral prefrontal cortex by an acute bout of moderate exercise under these conditions [26, 29].

Schroeter et al. reported that NIRS was a valuable tool for cognitive functional brain activation studies in an event-related design, as demonstrated for the color-word matching Stroop task [18].

Therefore, we measured changes in [oxy-Hb] by fNIRS during the Stroop task to monitor fatigue.

In the present study, the experiment was completed in 4 h in two subjects (subjects 1 and 3) due to a subjective feeling of fatigue and marked decreases in their waveforms. Another hour of work was performed by the remaining seven subjects.

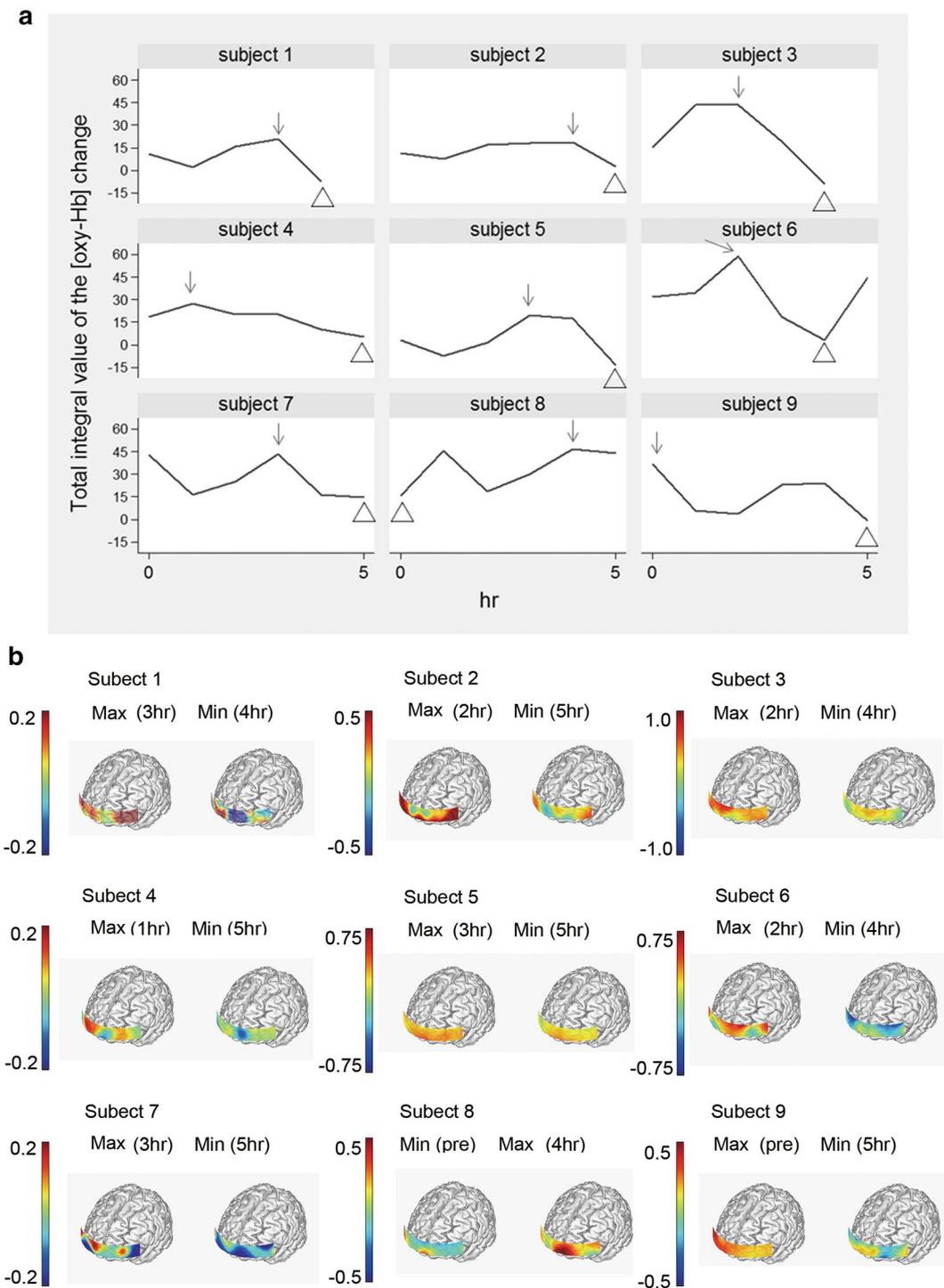


Fig. 4 a Time course of mean total integral values of [oxy-Hb] changes in the incongruent task for all nine subjects. The scale of the Y-axis is mM mm s. The arrow shows the maximum and the arrowhead the minimum [oxy-Hb] changes. **b** 3-D topographic map using the virtual registration method in nine subjects. The color bar repre-

sents the [oxy-Hb] change and the scale is mM mm. Each 3D topographic map is created at the same time point as the maximum (Max) and minimum (Min) values in medical imaging interpretation sessions. The time point was 2 m 20 s in subject 1, 3, 2 m 40 s in subject 2, 4, 5, 7, and 9, and 4 m 20 s in subject 6 and 8 (color figure online)

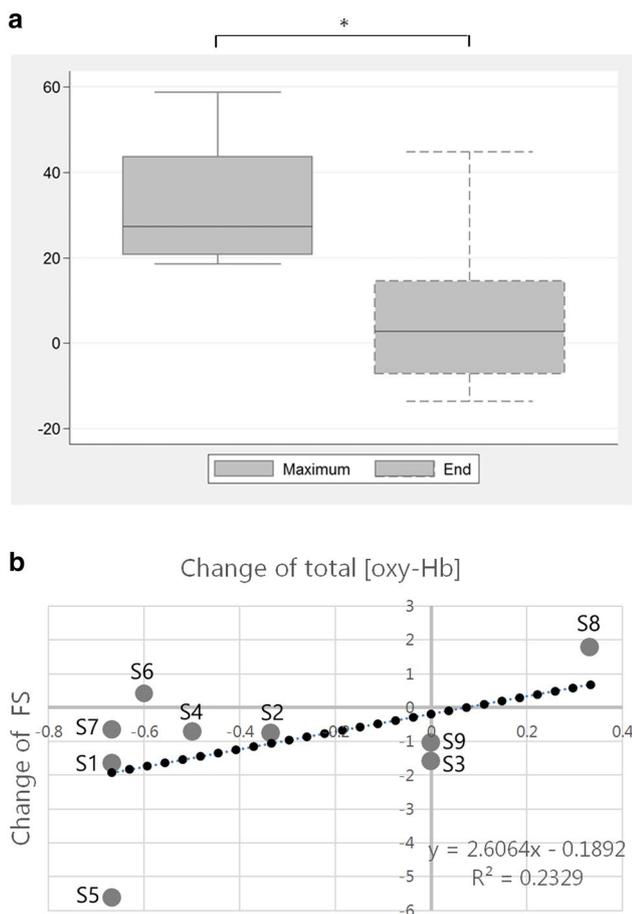


Fig. 5 **a** Comparison of mean total integral values of [oxy-Hb] changes in the incongruent task of all subjects between the maximum value over time and the values at the end. The scale of the Y axis is mM mm s. A significant difference was observed between the maximum value and end times ($P < 0.05$). **b** Relationships among percentage changes in FS and total [oxy-Hb] changes. Percentage changes in FS from the first to last times [ratio=(Last–First)/First %] ranged between –0.67 and 0.33%. Percentage changes in total [oxy-Hb] from the first to last times [ratio=(Last–First)/First %] ranged between –5.61 and 1.78%. Each subject was plotted on the scatter plot. Subjects 6 and 8 showed positive changes in FS. The Y-axis is change of total [oxy-Hb] and the X-axis is change of FS

Changes in [oxy-Hb] increased at the end of the experiment in two (subjects 6 and 8) out of the seven subjects who completed 5 h of continuous work, but decreased to its lowest levels in the remaining five subjects. Changes in [oxy-Hb] in the prefrontal cortex were generally less at the end of medical image interpretation than in the first half in most radiologists.

Lim et al. demonstrated the persistent effects of cognitive fatigue in the fronto-parietal network after a period of heavy mental work in mediating TOT effects, using an arterial spin labeling (ASL) perfusion study [15].

Gui et al. showed that TOT effects reduced resting spontaneous activity in the default mode network (DMN), and

exhibited resting-state amplitudes of low-frequency fluctuation (ALFF) decreases after prolonged attention workload in the posterior cingulate cortex and right inferior parietal lobule/angular, the medial prefrontal cortex, left inferior parietal lobe (IPL)/angular, left inferior frontal gyrus /anterior insula, and left superior frontal gyrus [8]. Impaired brain activity and network has been reported to be associated with mental fatigue of prolonged attention workload with functional brain imaging.

The present result showing that changes in [oxy-Hb] decreased after prolonged work in the prefrontal cortex is consistent with the previous findings.

In the previous studies, inter-individual differences were reported in vulnerability to fatigue responses to a long cognitive workload [8, 15, 31].

There are individual differences as to when maximum values peak. In addition, with regard to the brain activation site, specific areas could not be identified and there are individual differences in brain activation pattern in the present study.

Especially, when brain activation is increased, there is a tendency to maintain stable brain activation, but in a state where it is decreasing, brain activation is not stabilized.

Only in subject 8, FS recovered in the latter part and was the highest at the end of the experiment. The change observed in [oxy-Hb] also increased in the latter part. This result suggested that subject 8 might be more tolerant of the present experimental setting.

In subject 6, FS decreased with time and showed the lowest value at the end of the experiment. On the other hand, the change in [oxy-Hb] showed the lowest value after 4 h and then increased after 5 h.

We speculated that subject 6 made one last effort at the end of the experiment, because each subject was informed that the experiment was up to 5 h and that there may be a time lag between the subjective feeling of fatigue and brain activity. In the interview during the experiment, subject 6 answered as follows: “Subject 6 was actually so tired when four hours passed, but refreshed slightly for last one hour.”.

Therefore, considering the experimental situation, the change of fNIRS might be considered to be plausible.

Chalder’s Fatigue Scale is a commonly used scale [32]; however, in the present study, each subject answered questions regarding their current condition as simply as possible in a short time in their own words, because FS had to be assessed many times and quickly. Although FS decreased slightly as the experiment progressed, the standard deviation of each parameter was large and individual differences were noted.

Various factors are related to the fatigue of diagnostic radiologists in a complex manner, such as how many reports were completed, how complex a report was, and whether results were needed immediately for emergency cases. Since

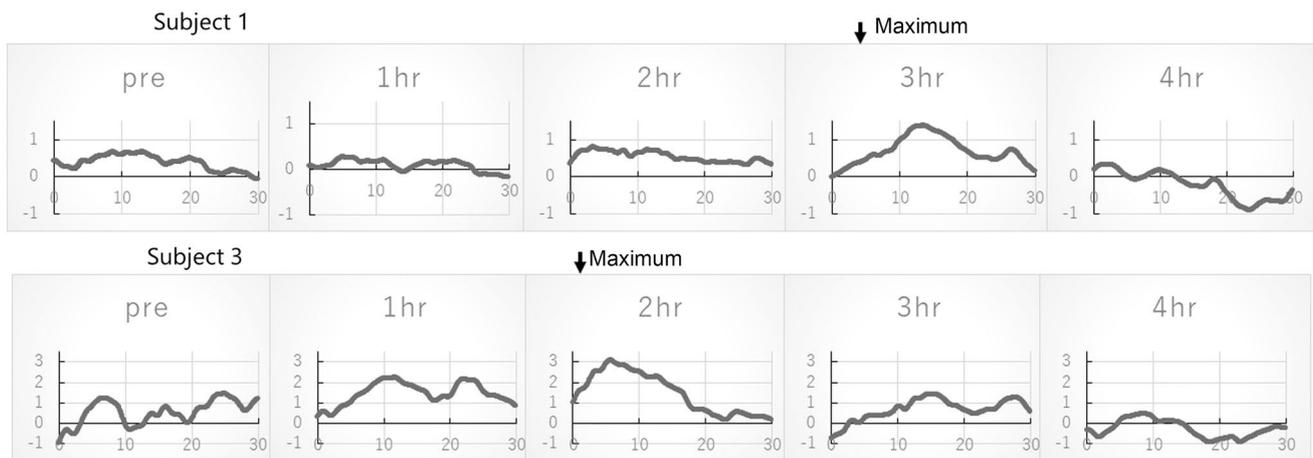


Fig. 6 Representative waveforms of mean total integral values of [oxy-Hb] changes in the incongruent task in subjects 1 and 3. The scale of the Y-axis is mM mm s. The scale of the X-axis is sec. Maximum times were 3 and 2 h in subjects 1 and 3, respectively

fatigue is a subjective feeling, difficulties are associated with evaluating it using an objective scale. In the present study, no relationship was statistically observed between FS and brain activity. We attributed this to the difficulties or complexities associated with the fatigue evaluation. Therefore, a method to objectively monitor fatigue as simply as possible is needed.

Reaction times are generally slower and accuracy is less in an incongruent task than in a neural task. In the present study, no significant differences were observed in reaction times or accuracy in the Stroop task between neural and incongruent tasks. One possibility is that radiologists are trained to identify small differences or abnormal findings in daily clinical practice. Therefore, it may have been difficult to observe differences between the neural and incongruent tasks in this experiment.

Image interpretation is an advanced cognitive function that requires visual attention and verification with memory, and its integration and optimization are repeated until a reliable answer is obtained. Although a large amount of information is input into the human visual system, not all of it may be handled [33]. Information is processed in order of priority, and this is called visual attention [33, 34]. There is a time limit for visual attention, with decreases occurring as time increases. Since brain fatigue is inevitable and leads to misdiagnoses, rest intervals are necessary for restoring brain function.

Limitation

The present study has several limitations. It did not include a control condition in which subjects were examined during the same protocol without the interpretation of medical images. Furthermore, the small sample size may have limited statistical power.

Inter-individual differences were noted. All subjects were allowed to drink beverages during image interpretation, similar to typical daily work conditions, which may have influenced brain activity. However, the purpose of the present study was to measure brain activity when usual work was performed for a long time; therefore, we asked each subject to perform the same work as usual. Two of the nine subjects drink coffee before the experiment or during the work.

Although it is thought that the apparent influence on fNIRS is scarce, it is actually difficult to evaluate this effect.

In future studies, we intend to investigate localization related to fatigue in more detail and develop strategies to effectively restore fatigue.

Conclusion

fNIRS enabled us to easily monitor the time course of changes in [oxy-Hb] from radiologist in a short time. Although inter-individual differences were observed in the pattern of waveforms, changes in [oxy-Hb] measured by fNIRS have the potential to evaluate fatigue in most radiologists performing image interpretation for long periods of time.

Further studies are needed due to inter-individual differences, with detailed research on each individual being necessary.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical statement This study was approved by the Institutional Review Board of Komaki City Hospital and Nagoya Jhohoku Radiology Clinic.

Informed consent A comprehensive explanation of the experiment was given to subjects before this study and written informed consent was obtained. Authors from multi-institute participant in this study, and each author individually and significantly contributed to the research and the manuscript.

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