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Hemodynamic change in occipital lobe during visual search: Visual attention allocation measured with NIRS.

Running head: Occipital Hb change with attention

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Abstract

We examined the changes in regional cerebral blood Volume (rCBV) around visual cortex using Near Infrared Spectroscopy (NIRS) when observers attended to visual scenes. The oxygenated and deoxygenated hemoglobin (Oxy-Hb and Deoxy-Hb) concentration changes at occipital lobe were monitored during a dual task. Observers were asked to name a digit superimposed on a scenery picture, while in parallel, they had to detect an on-and-off flickering object in a Change Blindness paradigm. Results showed the typical activation patterns in and around the visual cortex with increases in Oxy-Hb and decreases in Deoxy-Hb. The Oxy-Hb increase doubled when observers could not find the target, as opposed to trials in which they could. The results strongly suggest that active attention to a visual scene enhances Oxy-Hb change much stronger than passive watching, and that attention and Oxy-Hb increases are possibly correlated.

Key words: Near-infrared spectroscopy (NIRS); Hemoglobin concentration change; Visual cortex; Active attention; Change Blindness

Introduction

A visual scene consists of various objects and elements, and attention plays an important role in detecting and identifying one object among others. It has been known that visual task performance is highly influenced by attention, regardless of whether the task involves lower level processes or higher cognitive process (e.g. Treisman & Gelade, 1980; Nakayama & Mackeben, 1989; De Fockert, Rees, Frith & Lavie 2001; Freeman, Sagi & Driver, 2001). Human performance depends on how much of the attentional resources are effectively allocated to the task, whether attention allocation is active or passive, overt or covert. However, how attentional resources are allocated and/or the extent to which attention affects processing in the early cortical areas has been controversial.

Early data showed that when animals performed an object recognition task, attention enhanced the firing rates of cells in extrastriate cortex, but not in primary visual cortex (e.g. Moran & Desimone, 1985; Haenny & Schiller, 1988). Later studies, however, showed that the responses of cells in primary cortex were also modulated by the direction of attention (e.g. Motter, 1993; Ito & Gilbert, 1999). Brain imaging studies have also reported that attention alters the activation of primary cortical area (Brefczynski & DeYoe, 1999; Somers, Dale, Seiffert & Tootell., 1999; Martinez, et al., 1999). Many of these studies investigated the cortical locus of activation typically based on changes in BOLD signal, by using functional MRI, during tasks in which observers paid attention to a visual scene or an object. However, it is not known how the ongoing allocation and/or the degree of attention affect rCBV.

In the present study, we used Near-infrared spectroscopy (NIRS) to measure the changes in oxy hemoglobin (Oxy-Hb) and deoxy hemoglobin (Deoxy-Hb) concentrations, separately, in the occipital region of observers in a dual attention task. Since Jöbsis (1977) showed the availability of monitoring hemoglobin concentration change as an index of a cerebral activation, researchers have been trying to map the regional brain activity using NIRS (e.g.Watanabe et al., 1996). Recently, many attempts have been made to measure various brain functions with this technique, such as language recognition (Pena, 2003), visual perception (Taga, Asakawa, Maki, Konishi & Koizumi 2001; Maehara, Taya & Kojima, 2007), visuo-spatial identification task (Herrmann, Ehlis, Wagener, Jacob & Fallgatter, 2005), proprioceptive feedbacks (Shimada, Hiraki & Oda, 2005), arithmetic tasks (Hoshi & Tamura, 1993), and recognition of cooperative actions (Shibata, Suzuki & Gyoba, 2007). However, most of the tasks used in these studies involved a factor of attention in combination with the task load itself. Separating the cerebral activation by attentional load from the activation by engaging in the task itself is necessary to understand the properties of the cortical function.

We compared the Oxy and Deoxy-Hb changes in conditions in which observer’s attention to a visual scene was either active or passive as well as in cases in which they did or did not find a target. Here we proceeded from the assumption that if attention is allocated to a visual field, then the magnitude of activation in the occipital lobe depends on the degree of allocated attention. To control attention, we employed two parallel tasks, a numeral counting task and a visual search task with stimuli presented in a Change Blindness (CB) paradigm (Rensink, O’Regan & Clark, 1997). The merit using the CB paradigm in a NIRS study is that the visual search task becomes relatively difficult so that observers have to keep their attention onto the stimulus to find a target. In addition, the activation is free from motion processes or motion aftereffects. Thus, if we could observe activation in a visual area with CB stimuli, especially in the lateral occipital regions which correspond to intermediate visual processing areas such as V3, V5, and/or Occipitotemporal (OT) regions (Grill-Spector, Kushnir, Hendler & Malach, 2000), we can attribute it to the cortical activation for object recognition process rather than motion processes per se.

Methods

Observers

Twenty five undergraduate students from Kanazawa University voluntarily participated in the experiment. All observers had normal or corrected-to-normal visual acuity. They had a briefing on the procedure of the present study, and their informed consent for NIRS measurement was obtained.

Apparatus and NIRS setting

Stimulus presentation was controlled by a personal computer (Panasonic, CF-W4) and series of stimulus pictures were presented on a 22-inch CRT monitor (Dell, P1230). The display resolution was set at 1024 × 768 pixels with a refresh rate of 75 Hz.

A 24-channel NIRS instrument (Hitachi Medical Co., ETG-4000 Optical Topography System), which generates near-infrared lights of two wavelengths of 695 and 830 nm, was used for monitoring Oxy-Hb and Deoxy-Hb concentration changes with a sampling rate of 10 Hz. A set of 4 × 4 array photodiodes, comprising 8 light emitters and 8 detectors side by side with a distance of 3 cm, was placed on the occipital areas of the observers' head. The bottom array of the photodiodes was placed just above the inion, so that O_1 and O_2, as in the international 10-20 system, were located between channels 18 and 19, and 20 and 21, respectively. P_z was positioned at channel 2.

Stimuli

Visual stimuli comprised pairs of pictures. Each pair consisted of an original picture and a modified copy of the original. The original pictures were of casual, familiar sceneries of the university campus or Kanazawa city, taken with a digital camera. The pictures had 640 × 480 pixel sizes with a 24-bit color resolution. The modified pictures were made by erasing (or adding) one object, such as a tree, a cloud, or a car from the original picture. The gap was then filled with the background around the object. The missing object in the modified pictures was the "target". Each target was located at least within the range of 3 deg from the center of the pictures. Stimulus pictures as a whole subtended 13 deg width × 10 deg height in visual angle when presented on the monitor. The pairs of original modified pictures were presented successively, each for 1300 ms with a blank interval of 200 ms, by means of the CB paradigm. A random digit, each of which subtended 0.66 deg × 0.33 deg in visual angle, was occasionally superimposed on the pictures, also within the range of 3 deg from the center. In total, twenty pairs of stimulus pictures were prepared. The pairs were chosen from a large sample and were judged as roughly equally difficult.

Procedure

Observers sat 100 cm in front of the monitor using a chin rest. After 30 sec of initial relaxing time, the experimental session began. One experimental session consisted of ten repetitions of a task period alternating with a rest period, each of which lasted for 30 sec. In each task period, the observers were instructed to read aloud the digit appearing in the picture. In parallel, they were required to find the target, which was appearing and disappearing within the picture during the test period. Observers were asked to press a hand-held button as soon as they found the target. In each task period, a set of new pictures was presented as the stimulus. In the resting periods, only a white fixation point appeared at the center of the display, at which the observers were asked to keep looking. After the experimental session, observers were informed about what the missing objects were in each task period so as to check if they had found it correctly. We call this task condition hereafter the “attentional condition”.

Before testing the attentional condition, observers ran a control session. The procedure in the control session was the same as for the attentional condition except for the following. Observers were instructed just to read aloud the digit appearing in the set of pictures and press the button immediately when the digit was “0”. They were not informed about a disappearing stimulus target in the picture. After the ten repetitions of the control session, they were asked whether they noticed any on-and-off object, and verified the whether they had correctly found the target or not. We refer to this task condition as the “inattentional condition”.

In the both the attentional and inattentional conditions, observers had to maintain their attention onto the display, especially around the center, to name the digits. However, observers in the attentional condition had to make more attentional effort to engage in the dual task, i.e. to find the target, as compared to the inattentional condition with digit-naming only.

Results

Behavioral Data

In the attentional condition, the reaction time (RT) for finding the target objects ranged between 5.9 sec and 24.5 sec. and the percentage of “found” targets was 75.6 % overall (“found” trials). The observers could not find the target in the remaining 24.4 % of the trials (“unfound” trials).

In the inattentional condition, the observers responded perfectly when the target “0” was presented. They reported having found on-off objects inattentionally and involuntarily in 40.0 % of the all trials (“found” trials), while in the remaining 60% they did not find the target (“unfound” trials).

NIRS Data

We looked at trends in the raw data of Hb concentration changes over time, for found/unfound trials in each condition. Raw data were pre-processed with low-pass filter of 1 Hz. Then, first, Oxy-Hb and Deoxy-Hb data sequences were segmented from 10 sec before a task period to 30 sec after the task period. Next, the baselines of the sequences were corrected, based on the average during the 10 seconds prior to the task period. The baseline-corrected data for each observer were averaged according to found/unfound trials for the attentional and the inattentional condition.

-------------------- Figure 1 around here ----------------

Figure 1 shows the grand averages of the Hb change data for all observers, over all channels from 10 sec before the task period to 30 sec after the task period. Figure 1a represents the Hb changes in the attentional condition while Figure 1b represents the changes in the inattentional condition. In the attentional condition, Oxy-Hb vigorously increased after the beginning of the task period especially for “unfound” trials (Figure 1a, magenta), while Oxy-Hb in “found” trials moderately increased during the task period (Figure 1a, red). The mean of Oxy-Hb in the unfound trials during the task period in attentional condition, was significantly higher than the other three cases (Figure 1c).

Next, the Oxy-Hb and Deoxy-Hb changes during the task periods were examined, in each channel if they significantly increased or decreased from baseline, in each of four conditions, i.e. attentional/inattentional conditions and found/unfound trials. The mean Hb values during the last 10 sec of the task period in each condition were averaged and subjected to one-sided t-tests against zero. Markers in Figure 2 indicate the channels with significant changes. Significant activation changes between the conditions and the found/unfound trials were found in more channels for Oxy-Hb than for Deoxy-Hb.

-------------------- Figure 2 around here ----------------

We further examined the differences of the Oxy-Hb changes between the conditions by 3-way repeated measures ANOVA (attentional/inattentional condition × found/unfound × 24 Channels). Data for four observers who found all targets or could not find any target, were excluded from the ANOVA. There was a main effect of the factor “found/unfound” ($F(1,20)= 7.558$, $p<.05$), and “Channels”($F(23,460)= 8.829$, $p<.0001$). Interactions between attention condition and channel, and among the three factors were significant ($F(23,460)=2.227$, $p<.001$; $F(23,460)=2.374$, $p<.001$). Post-hoc comparison with Ryan’s method showed significant simple interactions in Ch 2, 9, 12, 13, 16, and 21, indicating that these channels reflected differential response in rCBV to the attentional conditions as well as the found/unfound trials (Figure 1d).

Discussion

In the attentional condition, the Oxy-Hb change became substantially high when observers could not find the target and thus kept attending to the visual scene. However, when observers could find the target the Oxy-Hb change merely rose to the same level as that in the inattentional condition. It was probably because observers no longer needed to pay attention to the stimuli once the target was found. These results indicate that the amount of Oxy-Hb change is related to the strength and/or the duration of attention paid. The high Oxy-Hb levels in "unfound" trials in attentional conditions can be explained by active and lasting attention producing a strong activation in the visual cortical area. The results, in other words, infer that active attention evokes stronger activation than passive attention, and that the longer attention is paid, the more the rCBV in the attention related cortical region increases. Our present results indicate that there are several stages in the amount of attention allocation, and that cortical activation changes with the attentional load such as its strength or duration.

According to Okamoto et al. (2004), the significantly different channels between the conditions were located along the parieto-occipital regions and lateral occipital regions (Figure 1d). The present result is consistent with the findings that attentive tracking of spatial targets produces parietal activation (Culham et al, 1998).

The activation in the lateral occipital region in our study is understandable as well, because in the attentional condition, the observers had to search and find an object. These lateral occipital areas, from dorsal V3a/b toward V5/MT (Larsson & Heeger, 2006), have known to show consistent activation during feature processing (e.g., Grill-Spector et al., 2000).

In summary, the present results showed that cerebral blood volume in the visual cortical area increased corresponding to the amount of attention used. The present study suggests the feasibility of investigating visual attention allocation by monitoring hemodynamic changes in each brain area.

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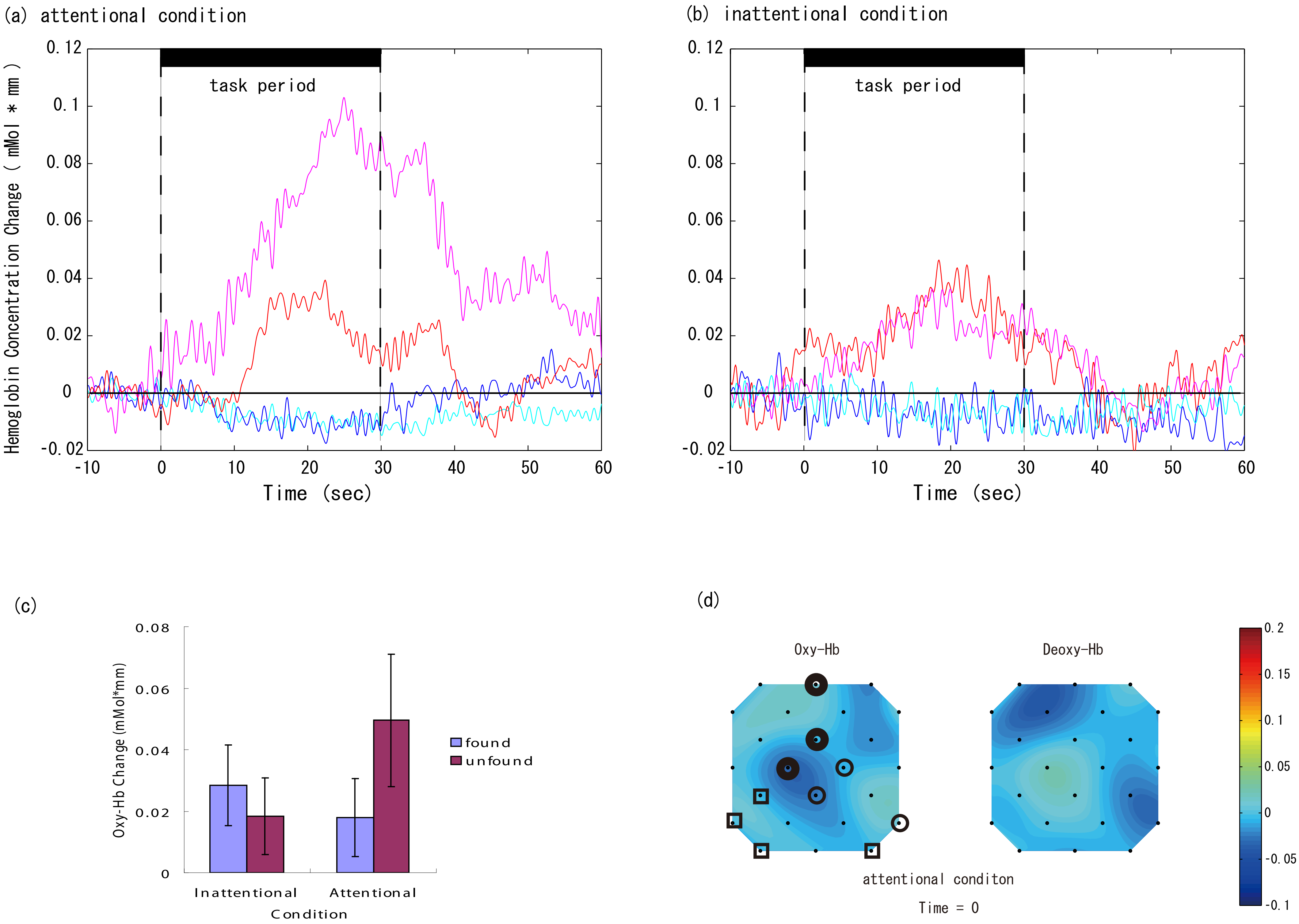
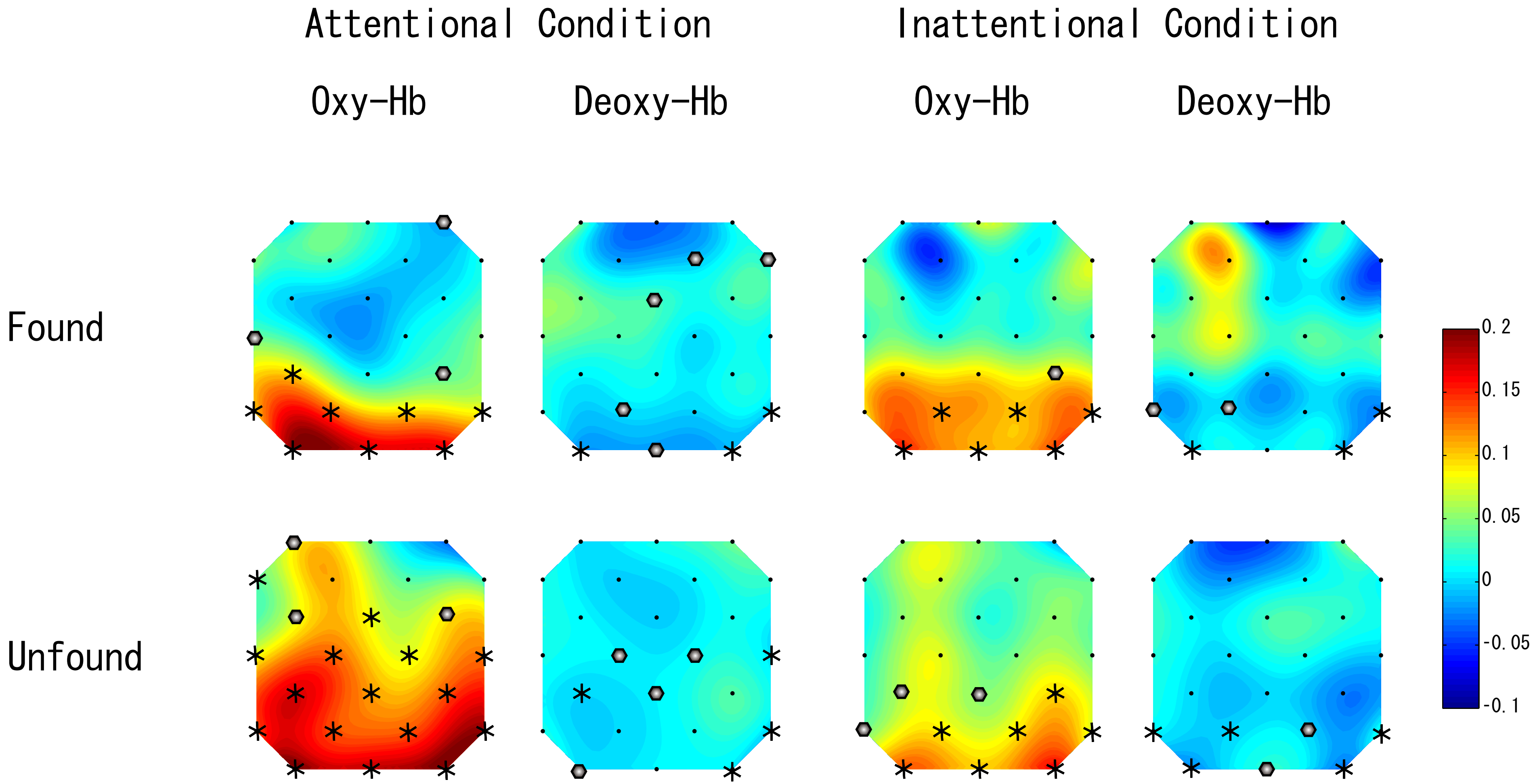
Figure captions

Figure 1. (a) Changes in the hemoglobin concentration over time, from 10 sec before the task period to 30 sec after the end of the task period, in the attentional condition. The time courses of the Oxy-Hb changes for “found” trials are drawn in Red and for “unfound” trials in Magenta. Deoxy-Hb changes for “found” are in Blue and “unfound” trials are in Cyan. Graphs are noisy because they are the simple grand average of the all the channels in the measured occipital area of all observers, including noisy channels. (b) The hemoglobin concentration changes in time, in inattentional condition. (c) Mean and standard error of mean of Oxy-Hb change during task period for the found/unfound trials in the attentional/inattentional conditions. (d) Channels which showed significant differences between the conditions and found/unfound trials. Squares indicate the channels which showed a main effect in the factor of attention ($p<.05$). Circles represent channels which showed significant interactions between the factors of attention and found/unfound trials (thin circle $p<.05$, thick circle $p<.01$). The maps are the state of the Oxy-Hb and Deoxy-Hb changes at the beginning of the task periods, time = 0 s, in the attentional condition. Color index indicates the magnitude of hemoglobin concentration change (mMol*mm).

Figure 2. Activation maps of the measured area at t = 20 s in the task period. The maps show the grand average from all observers, separately, of the Oxy-Hb and Deoxy-Hb changes, for “found” and “unfound” trials in the attentional and inattentional conditions. Color index expresses the magnitude of hemoglobin concentration change (mMol*mm). Asterisks represent the channels which showed Hb-change at the significance level of $p<.01$, while diamonds express $p<.05$.


(a) attentional condition
task period
Hemoglobin Concentration Change (mMol * mm)
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-10
0
10
20
30
40
50
60
Time (sec)
(b) inattentional condition
task period
Time (sec)
(c)
Oxy-Hb Change (mMol*mm)
0.08
0.06
0.04
0.02
0
found
unfound
Inattentional
Attentional
Condition
(d)
Oxy-Hb
Deoxy-Hb
attentional conditon
Time = 0
0.2
0.15
0.1
0.05
0
-0.05
-0.1


Attentional Condition
Inattentional Condition
Oxy-Hb
Deoxy-Hb
Oxy-Hb
Deoxy-Hb
Found
Unfound
0.2
0.15
0.1
0.05
0
-0.05
-0.1