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2 Reduction in Background Prefrontal Activity: A Near Infra-Red Spectroscopy (NIRS) Study

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In NIRS activation studies, baseline hemodynamic level was determined before experiment. Activations in the test and the control phase are expressed with reference to this baseline level. Researchers compare activations in the test with those in the control conditions without taking baseline level into account. However, as the default mode studies have suggested (e.g., Gusnard & Raichle, 2001), baseline level changes according to cognitive activities such as attention. In the present study, we observed the general reduction, or deactivation, of prefrontal hemodynamic activities in two experiments and discussed the functional meaning of the reduction.

I. Auditory Working Memory in absolute pitch (AP) possessors

Methods

Participants

Twenty-three right-handed volunteers (18–30 years of age) participated in this experiment. All participants underwent a screening test, in which they identified pitch classes by name. This is the general AP screening method

(Miyazaki, 2000). On the basis of the screening test, the participants were categorized into AP possessors or non-AP possessors. The AP possessors scored more than 90 % (average 97.6%), while the non-AP possessors scored under 30% (average 15.8%). AP possessors had spent an average of 13.2 years and non-AP possessors 5.1 years studying their principal instruments, mainly piano. This study was approved by the Ethics Committee of The Faculty of Letters of Keio University.

Apparatus

We used a multichannel NIRS system (ETG-7000, Hitachi Medical Corporation). The reflection of the infrared light was sampled every 0.1s by receiving probes. There were 22 channels for each holder over the left and the right frontal cortex (44 channels in total). The changes in both oxy-hemoglobin (oxy-Hb) and deoxy-hemoglobin (deoxy-Hb) were measured. We placed the channels with reference to the International 10–20 system. The central lower channel of the left hemisphere was placed on F7 and on F8 in the right hemisphere.

Stimuli and Procedure

Stimuli. Stimuli were synthesized piano tones and white noise. The fundamental frequencies were from C3 (261.6Hz) to C4 (523.3Hz). Each tone was 500 ms in duration, with a 50-ms quarter sine wave rise time, 350-ms steady-state portion, and 100-ms exponential decay. These stimuli were presented from a loudspeaker in a sound-attenuated room. The intensity of these sounds was about 80 dB SPL.

Procedure. The trial involved delayed matching to sample. Seven stimuli (sample sounds) were presented consecutively, with a 1-s stimulus presented after a 6-s delay interval (test tone). The participants were required to judge whether the third sample sound was the same as or different from the test tone. Thus, a trial was 10.5 s in duration with inter-trial interval of 4.5 s. There were two types of trials, Easy and Difficult. In the Easy trials, the third sound was a musical tone and the other six sounds were white noise. These trials were therefore easy for both groups. In the Difficult trials, all of the sample sounds, including the third sound, were musical tones; these trials were therefore easy for the AP processors but difficult for the non-AP processors. We employed a block design (Easy blocks with Easy trials and

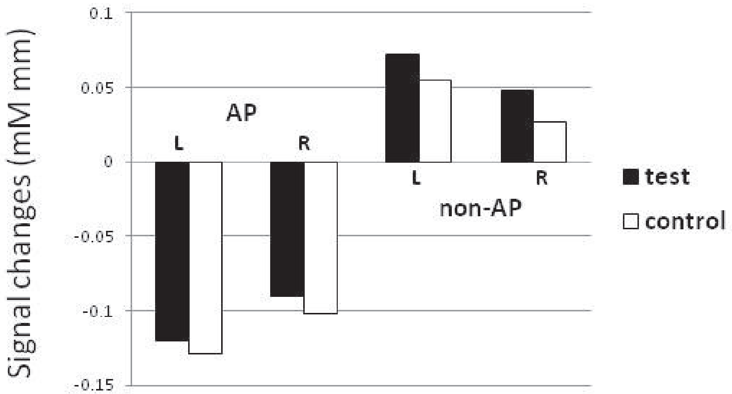

Figure 1. Mean left and right prefrontal oxy-Hb changes in the test (Difficult) and control (Easy) blocks for AP and non-AP possessors.

Difficult blocks with Difficult trials). Each block included 5 trials (75 s in duration). The Easy block was repeated 6 times and the Difficult block 5 times. Each session started with an Easy block, and then the Difficult, with 5 alternations. The duration of the experiment was thus 825 s.

Analysis of NIRS data. We examined the changes in concentration of oxy-Hb. We calculated the average change in concentration of oxy-Hb in the Difficult blocks and that in the Easy blocks for each subject. Data for channels with artifacts were omitted from analyses. The analysis began 7s after the onset of the block, and ended 7s after the end of the block (the analysis window). We then applied a 3-way (AP processors vs non-AP processors (participants), left vs right cortex (hemispheres) and difficult vs easy (blocks)) analysis of variance (ANOVA) to differences in changes in oxy-Hb.

Results

Behavioral results. In the Difficult pitch memory trials, the average correct response rate of AP processors was 99.3%, and that of non-AP processors was 64.3%. In the Easy pitch memory trials, AP processors and non-AP processors had 99.4% and 96.1% correct response rates, respectively.

NIRS results. Figure 1 shows mean oxy-Hb changes in the Difficult and Easy blocks and differences between these two blocks in both hemispheres. Three-way ANOVA indicated that non-AP possessors revealed significantly higher activation than AP possessors, F (1,21)=8.823, P=0.0073.

II. Motor Imagery in female participants

Methods

Participants

Seven right-handed undergraduate volunteers participated in the experiment. This study was approved by the Ethics Committee of The Faculty of Letters of Keio University.

Apparatus

The same NIRS system was used. In the present experiment, a 22-channel holder was placed symmetrically over the prefrontal cortex. The changes in both oxy-hemoglobin (oxy-Hb) and deoxy-hemoglobin (deoxy-Hb) were measured. For motor tasks, an L-shaped finger slit maze was used. See Ishizu et al. (2009) for details.

Procedure

Participants were asked to move their hand to the goal point with the right index finger along an L-shaped slit (width, 1.5 cm; length, 40 cm) carved on a cork board (43cm×30 cm). A knocking sound indicated the start and end of each trial. Following this sound cue, subjects started to move their hand along the slit with their right index finger, back and forth once between the goal and starting point over a period of 15 s. During the task, a metronome, which produced a steady beat (1 Hz), was used to help the subjects move their hands regularly at a uniform pace. Subjects were also asked to maintain a fixed hand form. Subjects practiced several times before proceeding to the experimental blocks and could perform the movement completely within 15 s. During the task and the practice session, subjects had their eyes closed to avoid getting any visual feedback. A block design was used as the experimental paradigm, consisting of 13 blocks, starting with the first control block of 20 s of rest, in which the subjects were asked to count metronome sounds and to keep their hands relaxed without making any movements, followed by the first test block of the 15-s hand movement, followed by alternate

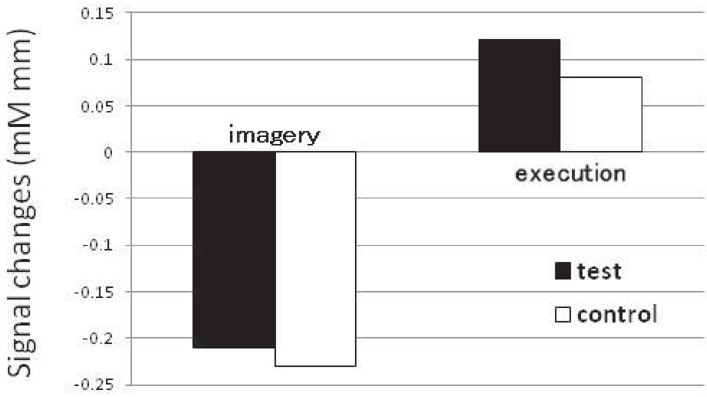

Figure 2. Mean prefrontal oxy-Hb changes in test and control phase during the motor execution and the motor imagery conditions.

control and test blocks and ending with a control block. There were a total of six control blocks alternating with five test blocks. During the experiment, changes in oxy-Hb and deoxy-Hb were recorded.

Subjects were instructed to imagine moving their hands on the board in exactly the same manner as they did in the motor execution experiment, taking the same time (15 s), but they kept their hands still and relaxed. The start and end of each trial was indicated with a knocking sound and timing was aided with the metronome. Other conditions were same as those in the movement execution experiment.

Results

Figure 2 indicates changes in oxy-Hb between the test and the control blocks for the movement execution and the imagery conditions. Although oxy-Hb increased in the motor execution experiment, it decreased both in the test and the control blocks during motor imagery. Two-way ANOVA indicated higher activation in the motor execution than in the motor imagery experiments ($F(1,6)=28.269$, $p=0.0018$).

III. General Discussion

We observed general reduction of oxy-Hb in the prefrontal cortex in two experiments: auditory working memory in AP possessors and motor imagery in female participants. It is important to note that there phenomena were observed in the block design experiments. Do these results have meaning? Usually a baseline oxy-Hb level of each participant is determined before experiment in NIRS studies. NIRS data in the experiment, that is, the test and the control conditions, are oxy-Hb changes with reference to this baseline level. We compare oxy-Hb differences between the test and the control condition without taking the baseline level into consideration.

In the present study, general reduction of oxy-Hb in the prefrontal cortex was observed, that is, oxy-Hb reduction in both test and control conditions. This reduction in oxy-Hb may have functional meaning. The prefrontal cortex was activated to problematic situations. In the first experiment, AP possessors, not non-AP possessors, reduced prefrontal activation. One possibility is that the auditory working memory task might be too easy for the AP possessors to activate the prefrontal cortex. Another possibility, which is related to the second experiment, is that internal rehearsal of multiple codes of the sample sound might reduce prefrontal activities (Zatorre & Beckett, 1989). The latter interpretation, however, has difficulty in explaining the results of non-AP possessors.

In the second experiment, female participants reduced prefrontal activities in the motor imagery task, not in the motor execution task. Imagery is closely related to internal rehearsal. Retrieval of external events from motor long-term memory (imagery) and working memory (rehearsal) might reduce prefrontal activities. Attention to external events often reduces activities in the medial prefrontal cortex (Gusnard & Raichle, 2001), which is covered in the present experiments. Is this applicable to internalized external events?

Another interpretation is that reduction in prefrontal activities may indicate protection of specific explicit internal or mental events from interference. There may be other interpretations. Further experiments are necessary to explain these phenomena.

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