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Original Article

Near-infrared spectroscopy can reveal increases in brain activity related to animal-assisted therapy

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Abstract. [Purpose] Previous studies have indicated that animal-assisted therapy can promote recovery of psychological, social, and physiological function in mental disorders. This study was designed as a pilot evaluation of the use of near-infrared spectroscopy to objectively identify changes in brain activity that could mediate the effect of animal-assisted therapy. [Subjects and Methods] The participants were 20 healthy students (10 males and 10 females; age 19–21 years) of the Faculty of Agriculture, Saga University. Participants were shown a picture of a Tokara goat or shack (control) while prefrontal cortical oxygenated haemoglobin levels (representing neural activity) were measured by near-infrared spectroscopy. [Results] The prefrontal cortical near-infrared spectroscopy signal was significantly higher during viewing of the animal picture than during a rest condition or during viewing of the control picture. [Conclusion] Our results suggest that near-infrared spectroscopy can be used to objectively identify brain activity changes during human mentation regarding animals; furthermore, these preliminary results suggest the efficacy of animal-assisted therapy could be related to increased activation of the prefrontal cortex.
Key words: Rehabilitation, Prefrontal cortex, Oxygenated haemoglobin

INTRODUCTION

Some institutions are introducing animal-assisted therapy (AAT) to psychiatric daycare programs; such programs are intended to assist patients with mental disorders by supporting rehabilitation during recovery from a mental disorder, stabilization of mental status, improving patient socialization and interpersonal communication, and acting as a second-line preventative. The integration of AAT into clinical psychology was first credited to an article published in Mental Hygiene by child psychologist Boris Levinson in 1962. Levinson reported that he could make significant progress with a disturbed child when his dog Jingles attended the therapy sessions[1]. Barker and Dawson reported that AAT was associated with reduced state anxiety levels for hospitalized patients with a variety of psychiatric diagnoses; in addition, Barak et al. reported that AAT for elderly schizophrenic patients enhanced socialization, daily life activities, and general well-being[2, 3]. In addition, Baun et al. reported that petting a bonded dog significantly decreased systolic and diastolic blood pressure, and that this response paralleled the relaxation induced by quiet reading[4]. Taken together, these previous studies demonstrate the effectiveness of AAT in enhancing psychological, social, and physiological markers of recovery from psychiatric disorders. However, the vast majority of the data are subjective, gathered through behavioural observation and questionnaire evaluation, and despite renewed interest in the psychiatric field, few studies have reported on the effects of AAT using objective criteria.

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Fig. 1. Tokara goat

Fig. 2. Shack

Although functional magnetic resonance imaging (fMRI), positron emission tomography (PET), single-photon emission computed tomography (SPECT), and other neuroimaging methods are available for measuring human intracerebral physiological responses, the large instruments and high costs limit their utility (and availability). Furthermore, these methods are vulnerable to movement artefacts, such as those caused by petting a therapy animal, which limits their ability to analyse cerebral responses to AAT in real time. Recent advances in optical encephalography have resulted in the development of near-infrared spectroscopy (NIRS). NIRS is non-invasive, using near-infrared light to optically penetrate the head to the depth of the cerebral cortex. The equipment is portable and small enough to allow real-time measurement of cortical activity with very good temporal resolution during daily activities; in addition, it is much less vulnerable to movement artefacts. NIRS was validated in 1993, when it was used by several independent research groups to measure cranial nerve activity[5, 6]. For measuring regional brain activity, NIRS calculates changes in the concentrations of oxygenated and deoxygenated haemoglobin ([oxy-Hb] and [deoxy-Hb]) in a cortical area[7, 8]. According to Aoki et al., no study evaluating AAT via NIRS has been published to date[9]. In this study, we aimed to determine if NIRS can be used as an objective technique for analysing cortical responses to interaction with animals. To this end, we used NIRS to measure brain activity in the prefrontal cortex (PFC) of healthy subjects during quiet wakefulness (resting, a negative control), and during viewing of a picture of an animal (experimental image) or a shack (control image). We chose an image of a farm goat, given its usefulness as a therapy animal.

SUBJECTS AND METHODS

A pool of 20 healthy students composed of 10 males and 10 females (mean age ± SD of 20.6 ± 0.7 years; range 19–21 years) of the Faculty of Agriculture, Saga University, was utilized as subjects in this study. All participants provided written informed consent after a complete explanation of the study, and the experiments were approved by the Ethics Committee of Saga University (approval number: 26-64).

The experiment was performed in a block design: one block consisted of a 30 s pre-task baseline, a 60 s task, and a 30 s post-task baseline. This block was continually repeated three times. Each subject sat on a chair with eyes open throughout the task, and with eyes closed throughout the pre- and post-task periods. Two image-viewing tasks were used, one in which subjects viewed a picture of a Tokara goat (Fig. 1), and another in which subjects viewed a picture of a shack (Fig. 2) .

We used a wearable 22-channel NIRS system (WOT, Hitachi Corporation, Japan) to evaluate activation in the PFC. A portable processing unit for controlling the optical measurements was connected to the probe unit through a flexible cable bundle. The processing unit sent data to a personal computer that controlled the experiment through a wireless local area network. This system imposed no restrictions on movement due to wiring, and allowed subjects to work freely within the area covered by the wireless network signal. The NIRS system consisted of eight emitters and eight detectors, resulting in 22 channels consisting of one source-detector pair each. The distance between source and detector probes in a channel was set to 3.0 cm. The lowest probes were positioned along the Fp1–Fp2 line according to the international 10–20 system used in electroencephalography. Changes in the concentrations of oxy- and deoxy-Hb were calculated from changes in the absorbance of 705 and 830 nm light according to the modified Beer-Lambert law[10, 11]. We used changes in oxy-Hb values as indicators of changes in regional cerebral blood volume. Because oxy-Hb is more sensitive than deoxy-Hb as a parameter for measuring blood flow changes associated with brain activation, we used oxy-Hb changes to represent changes in blood volume[12, 13]. The start of a session was manually marked on the NIRS data.

Though less vulnerable than neuroimaging techniques, NIRS can still have movement artefacts. Thus, we first removed the trials that included movement artefacts, which were detected as sharp changes in the time series of the raw NIRS data. The

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remaining raw oxy-Hb data from individual channels were digitally high-pass filtered at 0.02 Hz to remove any longitudinal signal drift[14]. The mean concentration at each channel within a subject was then calculated by averaging data across the trials in a time series with 0.1 s epochs, beginning 1 s before trial onset and ending 1 s after trial offset. The mean concentration value of 1 s immediately before a trial was used as a baseline. From the mean concentrations in the time series, we calculated the Z-scores for oxy-Hb in the upright and inverted face condition for each channel within a subject. Because the raw NIRS data represent relative values within channels, they required normalisation (via conversion to Z-scores) to allow averaging across channels and subjects[15]. The Z-scores were calculated as the difference of the means of the baseline and a trial, divided by the standard deviation of the baseline, according to the following equation:

$$d = (m1 - m2) / s$$

Accordingly, "$m1$" and "$m2$" are the mean concentration values during the baseline and trial, respectively, and "s" is the standard deviation of the baseline. The Z-scores obtained from the 22 channels within each measurement area were then averaged to increase the signal-to-noise ratio. Previous studies have shown that the hemodynamic response typically lags behind the stimulation for a few seconds, peaking around 8 to 10 s after stimulus presentation[14]. Therefore, the haemodynamic response would reach a peak after the end of the 5-s-long trials. We determined to make statistical analyses against the mean Z-scores of the 10–20 s of the trials in order to avoid data including motion artefacts.

All statistical analyses were carried out with SPSS version 23.0 for Windows. Friedman's test of variance, followed by a Wilcoxon signed-rank test, was used to compare the averaged Z-scores of the "rest" and "shack" conditions to the "goat" condition. The significance level was set at $p < 0.05$.

RESULTS

When subjects viewed the Tokara goat image (i.e., the "goat" condition), NIRS measurements showed significantly higher Z-scores ($p = 0.011$) than when subjects were at rest (the "rest" condition). Z-scores was also significantly higher ($p = 0.001$) in the "goat" condition than the "shack" condition (i.e., viewing the shack image).

DISCUSSION

The purpose of this pilot study was to begin to evaluate the use of NIRS as a method for objectively analysing the effects of AAT.

We used a picture of a Tokara goat to represent interaction with an animal, and a picture of a shack to represent simply viewing an image. The goat image significantly activated the PFC relative to the shack image (as well as to the rest state). These results suggest the image of an animal specifically activated the PFC, implying that AAT may also do so. Previous work implicates the dorsolateral PFC in working memory[15], which is responsible for the temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning[14]. Smith et al. have reported that spatial memory predominantly involves right hemispheric regions, whereas verbal memory is predominantly left-hemisphere localized[16]. Activation of the PFC by AAT could generate improvements in socialization or working memory during psychiatric rehabilitation. Memory of the image could be evoked by touching the goat; in addition, AAT evokes multisensory (e.g., touch, sight, hearing) stimulation, so the effects of AAT may be more easily measured than the effect of viewing the image alone.

As a next step, as well as investigating the effects of AAT on other cognitive abilities (e.g., planning, organizational ability, and skill learning) and in people with psychiatric disorders.

There are some limitations to the present study. First, the sample size was small and not randomly selected. Second, the cost-effectiveness and social outcomes of this program remain to be examined. Third, we evaluated only PFC activity, and further work is needed to validate our findings here and begin analysing other cortical areas. Finally, it is possible that functional haemodynamics might not be associated with changes in neural processing per se, but could rather be a consequence of neurodegeneration and cortical atrophy related to specific psychiatric disorders. NIRS sensitivity is dependent on the scalp-to-cortex distance, so future studies should address the impact of anatomical differences due to degeneration or cortical atrophy, perhaps via correlational studies with neuroimaging modalities. In addition, extra-cortical physiological responses such as blood pressure, heart rate and skin blood flow can influence NIRS measurements, and so will need to be taken into account.

In conclusion, the present study suggests that AAT may evoke physiological changes in brain activity, at least in the PFC. This activity can be measured by NIRS, suggesting that this spectroscopy system could be utilized as a non-invasive analytical method to study brain activity in freely-behaving people undergoing AAT.

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