Changes in Task-associated Cerebral Blood Induced by Role Lettering: Measurement by Multichannel Near-infrared Spectroscopy

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Summary: Using optical topography (near-infrared spectroscopy: NIRS), relative changes in oxidized hemoglobin (oxy-Hb) were measured before and after the introduction of Role lettering. Tasks performed during measurements included antegrade (from the subject to other persons) and retrograde (from other persons to the subject) mental imaging and writing tasks. All subjects were junior high school students. Relative changes in oxy-Hb were measured before and 3, 6, and 12 months after the start of Role lettering. The region of interest (ROI) was determined based upon the motor cortex region of hand movement and upon relative oxy-Hb changes noted before any Role lettering. For antegrade mental tasks, oxy-Hb increased significantly in right-sided ROI after 3 months; this increase persisted at 1 year. For retrograde mental tasks, oxy-Hb significantly increased bilaterally at 3 months, an effect that also persisted at 1 year. With the antegrade writing task, no significant difference was observed throughout the study; with the retrograde writing task, oxy-Hb level decreased significantly in right lateral ROI after 6 months; the decrease persisted at 1 year. The number of words produced after Role lettering increased significantly in both antegrade and retrograde writing tasks at 1 year, compared with the number before Role lettering. Role lettering thus altered mental activity, particularly in the right hemisphere. Retrograde writing tasks, similar to those employed in the actual practice of Role lettering, reduced right hemispheric function; continuation of the task enhanced performance. Role lettering studies using NIRS may provide useful psychophysiologic indices.

Key words near-infrared spectroscopy, role lettering, right hemisphere, neuroimaging

INTRODUCTION

Writing therapy is often carried out in conjunction with traditional verbal psychotherapy [1-3]. Such writing has enhanced communication within couples, facilitated discovery of forgotten trauma, and promoted self-realization through self-analyzed assignments [1]. Most psychiatric and mental health professionals have experience with some form of writing as a tool for encouraging patients to express feelings and identify stressors [2]. Writing also can help patients to identify areas of conflict in their lives and is a useful technique that complements ongoing counseling for medical and surgical patients [3].

All therapists must deal with patient psychological defenses and resistance during the therapeutic process.

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Abbreviations: NIRS, near-infrared spectroscopy; oxy-Hb, oxidized hemoglobin; ROI, region of interest.
Role lettering shows promise as an effective treatment for problems resulting from such defenses and resistance because it addresses patients’ paradoxical desires for both self-disclosure and confidentiality in therapy sessions, and this therapeutic exercise is useful in promoting objective self-assessment and personal security by relating oneself to others and others to oneself [5]. As bullying and suicide in junior high school students have recently become more frequent in Japan, appropriate preventive measures based on educational psychological methods, including Role lettering, are needed. Role lettering entails a mental recall task, performance, and insight function [5]. In practicing Role lettering, those performing the task voluntarily write down how another person thinks of them, which tends to nurture the objective ego, as described above, presumably by cerebral processing. We therefore consider that investigation of cognitive function is important in understanding the mechanism of Role lettering.

Cognitive function involves serial information processing, in which large amounts of external information are incorporated and integrated for attention, memory, and motivation, leading to responses to the external environment through movement and the autonomic nervous system [6,7]. This cognitive function is very important in social activities, such as human relationships. Furthermore, emotions, such as joy and sorrow, and the affective responses that they induce, are particularly important for interpersonal relations [8-10]. Conditions accompanied by negative emotions, such as deep sorrow and distress, negatively impact interpersonal relations and cause irrational behavior [11]. Near-infrared spectroscopy (NIRS) can non-invasively measure oxidized hemoglobin (oxy-Hb) and reduced hemoglobin in blood vessels at the brain surface using scattered near-infrared light [12-14]. Although spatial resolution is low (2 to 3 cm), the temporal resolution of NIRS (0.1 seconds) is higher than in other cerebral blood flow evaluation methods. The measuring device is relatively compact and portable. In addition, dynamic changes in brain function can be visualized by converting the hemoglobin data to a 2-dimensional image. Suto et al. [15] measured changes in oxy-Hb during a word fluency task, concluding that oxy-Hb measurements can serve as a useful psycho-physiological index reflecting cognitive function. Ishii, et al. [16] simultaneously measured oxy-Hb and eye movements using an original method, observing changes in oxy-Hb during an emotionally loaded task performance, and they also suggested that NIRS is a useful tool to investigate emotional cognitive function.

However, the usefulness of Role lettering in biologic evaluation has not been studied and the mechanism is unclear. We therefore non-invasively investigated task-associated relative changes in oxy-Hb by NIRS before and after introducing Role lettering for a period of up to 1 year.

MATERIALS AND METHODS

Subjects

Subjects were 16 junior high school students (age, 12.1±0.8; boys, 13; girls, 3). No subject had a psychiatric illness or motor system disease. No subject had carried out Role lettering prior to session 1; afterward, they performed Role lettering once a week for 12 months at school [5]. All subjects were right-handed and carried out writing tasks with their right hand. The ethics committee of Kurume University approved the present study. Written informed consent was obtained from all subjects and their parents prior to any participation in the study.

NIRS measurements

Relative changes in oxy-Hb were recorded during tasks, using a multichannel NIRS instrument (ETG4000; Hitachi, Tokyo) in frontal (22 channels, Ch) and right and left lateral recording regions (24 Ch each) [16,17]. Tasks performed by subjects during measurements were as follows.

Mental imaging tasks: The subject imaged a verbal thought, ‘once upon a time...’ as a resting state. Old folk tales beginning in this manner are very popular in Japan and were well known to all subjects. The subject then imaged some type of positive affective thought from himself toward 5 persons in different relationship classes (friend, mother, father, teacher, and special friend) as an antegrade task, and then from each of these persons toward himself as a retrograde task, at 30-second intervals. Averaged waveforms for the 5 tasks were measured, and changes in oxy-Hb from the resting state were converted to numeric values every 100 ms. The mean value of oxy-Hb 5 seconds before and 5 seconds after the resting state was considered to be the baseline, and changes in oxy-Hb were observed between tasks and between the baseline. Changes in the area under the waveforms during performance of each task for 30 seconds were also determined [17].

Writing tasks: The subject wrote the once-upon-a-time story to establish a resting state, and ‘from me to five kinds of persons (friend, mother, father, teacher, special friend) as antegrade tasks, and ‘from five kind
of persons (friend, mother, father, teacher, special friend) to me’ as retrograde tasks with 30-second resting intervals, respectively. The averaged waveforms in the 5 tasks were measured, and compared with the resting-state. Oxy-Hb level was converted to numerical values every 100 ms [17] and the waveform area during performance of each task (30 seconds) was calculated.  

**Regions of interest (ROI) (Fig. 1 and 2)**  
In the present study, ROI were evaluated to determine physiologic significance. Motor-related channels were selected based upon the motor effect when the right hand was moving as. Role writing-related channels were also selected during the retrograde Role lettering task at session 1, as shown in Fig. 1. We considered Ch19, 21, 22, and 24 as right recording channels, and Ch6, 8, 9, and 11 as left recording channels; and Ch10, 14, 15 (left frontal), Ch11, 12, 16 (paramedical frontal), Ch13, 17, 18 (right frontal) as front recording channels.  

**Statistical analysis**  
Oxy-Hb data were examined using one-way repeated measures analysis of variance (ANOVA), with respect to session to evaluate epsilon factors and determine the session effect in each task. A Scheffe test was applied post hoc to identify significant differences between sessions. A probability value lower than 5% was considered to indicate statistical significance. The correlation between oxy-Hb and number of words produced was expressed as Pearson’s product-moment correlation coefficient (r); Bracelet’s t test was used to evaluate statistical significance. Values are presented in the text as the mean ± standard deviation (SD).  

**RESULTS**  

**Antegrade mental task**  
During the antegrade mental task, a session effect upon oxy-Hb in right-sided ROI was apparent in results of one-way repeated ANOVA \([F=4.26, p<0.01]\). Oxy-Hb was significantly increased in right-sided...
ROI at 3 months (p<0.05) as compared with that before introducing Role lettering; this effect persisted at 1 year (6 months, p<0.05; 12 months, p<0.05). However, no significant difference in oxy-Hb was noted in left lateral or frontal sites.

**Retrograde mental task (Fig. 3)**

During the retrograde mental task, a session effect upon oxy-Hb was demonstrated in right lateral ROI [F=12.23, p<0.0001] and left lateral ROI [F=4.06, p<0.01] by one-way repeated ANOVA. In right lateral ROI, oxy-Hb was significantly increased at 3 months (p<0.001) compared with that before the introduction of Role lettering, an effect persisting at 1 year (6 months, p<0.0001; 12 months, p<0.0001). In left lateral ROI, oxy-Hb level increased significantly at 6 months (p<0.05) and 12 months (p<0.05) as compared with the baseline before Role lettering. However, no significant difference in oxy-Hb was found at any frontal sites.

**Antegrade writing task**

There were no significant differences among sessions during the period of Role lettering over a period of 12 months. The antegrade writing task did not significantly alter oxy-Hb level, suggesting that writing a diary may have little activating effect.

**Retrograde writing task (Fig. 4)**

During the retrograde writing task, a session effect upon oxy-Hb in right lateral ROI was evident by one-way repeated ANOVA [F=6.80, p<0.001]. Oxy-Hb decreased significantly at 6 months (p<0.01) compared to that before the start of Role lettering, a change that persisted at 12 months (p<0.01). However, no significant difference in oxy-Hb was noted at left lateral or at frontal sites.

**Number of words (Fig. 5)**

As for number of words, the number increased significantly at 1 year from the number before introducing Role lettering in both antegrade (F=21.53, p<0.0001) and retrograde tasks [F=21.90, p<0.0001].

The number of words in the antegrade task at 1 year after Role lettering correlated negatively with oxy-Hb (r=−0.344, p<0.01) only in right lateral ROI. By channel, the number of words in the antegrade task correlated positively with oxy-Hb in left channel 5 (r=0.525, p<0.05). The number of words in the retrograde task at 1 year after Role lettering correlated negatively with oxy-Hb (r=−0.318, p<0.05) only in right lateral ROI. By channel, the number of words in the retrograde task correlated negatively with oxy-Hb levels (r=−0.606, p<0.05) only in right channel 24.
Fig. 3. Regional relative changes in oxy-Hb during retrograde imaging task before (Pre.) and up to 12 months (M) after beginning Role lettering. Left, selected recordings. Red color indicated the plus levels in oxy-Hb, and blue color indicated the minus levels in oxy-Hb. Right, Oxy-Hb vs. time point. ○, left lateral (LL); ●, right lateral (RL); □, left frontal (LF); ■, right frontal (RF); △, paramedical frontal (PF). *, p < 0.05; **, p < 0.01; ***, p < 0.001.

Fig. 4. Regional relative changes in oxy-Hb during the retrograde writing task before (Pre.) and up to 12 months (M) after beginning Role lettering. Left, subtracted oxy-Hb changes (Subtract 12M from Pre.)-and selected waveforms. Blue color indicated the minus levels. Oxy-Hb was high on both left and right sides. Right, Oxy-Hb vs. time point. ○, left lateral (LL); ●, right lateral (RL); □, left frontal (LF); ■, right frontal (RF); △, paramedical frontal (PF). *, p < 0.05.
To appreciate the function of Role lettering, the concept of writing therapy must be well understood. Writing therapy has attracted much attention, and writing exercises are often completed as homework assignments for use in conjunction with traditional verbal psychotherapy [1,2]. Writing has been found to increase communication within couples, and has encouraged self-realization through self-analysis of assignments [1]. Most psychiatric and mental health professionals have some experience with writing as a tool for enabling patients to express feelings and identify stressors more readily [2]. Writing can be used effectively with patients who are reluctant or embarrassed to speak openly in one-on-one interactions [2]. Thus, expressing one’s thoughts, feelings, and urges in writing transforms primary process activities of the self into secondary processes that are more mature and adaptive to healthy functioning in day-to-day living [4]; however, the biological mechanism of writing therapy is unknown.

Activity related to event-related potentials reflecting cognitive function was detected by NIRS; the affected region may have included the lateral frontal gyrus [17], and the authors indicated that left channel 6 might (Fig. 1,2) be a middle prefrontal region. According to Yamamoto et al. [17] channel 24 may be an inferior frontal region related to imaging [18]. In fMRI studies, the left dorsolateral prefrontal cortex [19], considered to be involved in working memory, was activated during task performance [20]. Activities related to the right hemisphere include those detected during drawing tests [18]. The main difference between Role lettering and writing therapy is the retrograde writing task. On recording during the retrograde writing task, right hemispheric activity before introducing Role lettering was greatly elevated in Ch22 and 24 (See Fig. 1 and 2), with the maximum recorded at Ch24, a relatively frontal location. Before Role lettering practice, no significant correlation was obtained between the number of words and oxy-Hb changes; however, a significant negative correlation was detected between the number of words and oxy-Hb levels (r= – 0.606) only in right Ch24 after 12 months. These results indicate that the area in Ch24 may be the most important area for Role lettering practice. A responsive search score for exploratory eye movement has been reported to be a psychophysicologic index reflecting interpersonal relations that relates to right hemispheric function [21]. The score is a numeric presentation of the visual field of exploratory eye movement after the subject reports the completion of identifying differences in a visual task. Attitude with latitude is considered of principle importance in interpersonal relationships. Accordingly, asking the subject whether any further difference is present, as opposed to making a simple com-

**DISCUSSION**

Fig. 5. Changes in total number of words. A: Antegrade writing task, before Role lettering (Pre.) and after 12 months (M). B: Retrograde writing task, before Role lettering (Pre.) and after 12 months (M). n = number of words. ***, p<0.001.
parison, is important for establishing the interpersonal condition from the other person to oneself, as in the retrograde writing task.

The changes in oxy-Hb during the antegrade writing task before Role lettering in right and left ROI were significantly smaller than that during the retrograde writing task. During the antegrade writing task, oxy-Hb did not change significantly over a period of 1 year. The retrograde writing task, however, significantly decreased oxy-Hb at 6 months compared to oxy-Hb before introducing Role lettering; the decrease persisted at 1 year and was detected only in the right recording region. This task most closely resembled the practice of Role lettering, suggesting that the right hemisphere became more weakly activated through training and learning in Role lettering in spite of an increase in the number of words used. This may increase the efficacy of imaging other persons' thoughts in the retrograde task. Liu et al. [22] reported that the middle frontal area and fusiform gyrus were activated following word training and familiarity with the writing system. Emotion is of fundamental importance in human relationships and determines human behavior. The effects of emotion should be present during Role lettering. It has been reported that the right hemisphere appears to be concerned with emotional processing [23]. Emotional effects have also been studied with NIRS [10,24]. Marumo et al. [24] reported that right lateral prefrontal cortex might be related to negative emotional stimuli and showed gender differences. Furthermore, the right frontal systems showed more activation with novel cognitive strategies and this area is organized principally to process novel challenges [25]. Thus, the decrease in the right oxy-Hb level after Role lettering indicates the possibility that the effect of emotion became weak after practice.

During the antegrade mental task, oxy-Hb was significantly increased at 3 months compared to oxy-Hb before introducing Role lettering; this increase persisted at 1 year. While the increase was detected only in right recording regions at 3 months, it had become bilateral at 1 year. The right hemisphere is related to imagination, while the left subserves speech and logic, suggesting that the right brain is selectively activated by the act of imaging [13,18]. The retrograde mental task also significantly increased oxy-Hb at 3 months compared to oxy-Hb before introducing Role lettering; the increase persisted and became bilateral at 1 year. Additionally, the left-sided component of activation from the retrograde mental task suggests that Role lettering facilitated activation of the left as well as the right hemisphere during that mental task [13].

Further characterization of the active region is necessary, especially for right brain function. Investigation of a larger number of subjects and more detailed analyses of individual subjects are also necessary. It should be considered that the temporal gyrus is associated with emotions and memories, while the insula has been linked to self-recognition and the evaluation of judgment [18]. Thus, structures slightly below the lateral recording regions may have included the temporal gyrus and insula [18]. As the region of the present observed changes in oxy-Hb may be related to the temporal gyrus, more definitive localization by fMRI is necessary during the retrograde writing task.

Finally, Role lettering can help to restore a sense of self-security, patience, and an understanding of how others feel. Oxy-Hb decreased significantly only in right recording regions, suggesting that subjects became more able to objectively observe and describe themselves while thinking about themselves as viewed by other person as they practiced Role lettering. The retrograde writing task may be difficult before practice. Nevertheless, healthy persons are able to perform the task, which initially appears to involve a marked increase in brain activity [18]. Unfamiliar strategies, such as the retrograde writing task before Role lettering practice, may therefore become familiar [25]. Persistent practice may enhance skill in performing the task as the result of familiarity [23,26]. Role lettering should act with other therapeutic techniques used in combination [1,2]. By training and continuation, people become able to readily understand and perform the task, suggesting that plasticity of the cortical network for emotionally related imaging may contribute to adaptations related to Role lettering practice. Role lettering therapy is therefore a useful contribution to transactional analysis therapy.

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