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NIRS-BASED NEUROFEEDBACK TRAINING TO TREAT DYSPHAGIA

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ABSTRACT: Neurological patients often show difficulties in swallowing, so-called dysphagia. Here we investigated whether motor imagery of swallowing during neurofeedback activates brain areas, which are involved in swallowing, and consequently fosters neuronal plasticity. Based on findings in healthy individuals, we performed a NIRS-based neurofeedback training (4 training sessions over 2 weeks) with one male stroke patient with dysphagia, in which the patient tried to modulate the hemodynamic response over the swallowing motor cortex by motor imagery while receiving real-time feedback of changes in the NIRS signal. Before and after the training, brain activation patterns during active swallowing were assessed offline. A healthy male control subject performed the same training. Both subjects were able to modulate the NIRS signal in a desired direction during neurofeedback training. The stroke patient also showed changes in maladaptive brain activation patterns elicited by active swallowing due to neurofeedback training. These results indicate the potential value of NIRS-based neurofeedback using motor imagery of swallowing to treat dysphagia.

INTRODUCTION

Dysphagia, which is a difficulty in swallowing, is a common consequence of brain lesions since swallowing activates a large network of cortical and subcortical brain areas [1, 2]. More than two thirds of stroke patients show dysphagia symptoms [3]. Swallowing difficulties are also prevalent in neurologic healthy elderly (13.5%-16%) [4, 5]. Dysphagia often causes chest infection and malnutrition and is associated with a slower rate of recovery, poorer rehabilitation potential and mortality [6, 7]. Natural recovery of post-stroke dysphagia can range between 6 months and 4 years after stroke onset [3, 8].
Here we investigated whether motor imagery of swallowing can be used to activate brain areas, which are involved in the swallowing process, to foster neuronal plasticity. A large portion of brain-computer interface (BCI) and neurofeedback (NF) training studies successfully showed that receiving real-time feedback about the activity in motor brain areas while imagining limb movements can be used to foster neuronal plasticity and consequently improve motor functions [9–25]. Prior near-infrared spectroscopy (NIRS) studies showed that healthy individuals as well as stroke patients generally show comparable brain activation patterns during executing and imagining swallowing movements [26–29]. Both tasks lead to the strongest NIRS signal change over the inferior frontal gyrus (IFG), which is part of the swallowing network [1, 28]. Healthy young adults are also able to modulate voluntarily the NIRS signal in a desired direction during NF training [27, 30].
The aim of the present proof of concept study was to investigate whether a stroke patient with dysphagia is also able to modulate the activity in the swallowing motor cortex when imagining swallowing movements during NIRS-based NF training. To reveal possible neuronal plasticity processes due to NF training, we examined brain activation patterns elicited during active swallowing before and after NF training, too.

MATERIALS AND METHODS

Participants: A 70-years old male stroke patient with multiple brain lesions in the right hemisphere (4 months after stroke) participated in this study during his stationary stay in the rehabilitation clinic Judendorf-Straßengel. The patient showed no psychiatric symptoms or cognitive deficits. The patient showed a moderate dysphagia at the beginning of the NF training (Bogenhauser Dysphagia Score BODS of 3) [31, 32]. During his stay in the rehabilitation clinic, he additionally received traditional logopedical treatment. Additionally, we investigated a 78-years old male subject with no neurological deficits and no dysphagia symptoms as control subject. Both participants gave written informed consent. The study was approved by the Ethics Committee of the University of Graz, Austria (reference number GZ. 39/25/63 ex 2013/14) and is in accordance with the ethical standards of the Declaration of Helsinki.

NIRS-based NF training: To assess the NIRS signal change (relative concentration changes in oxygenated oxy- and deoxygenated deoxy- hemoglobin Hb) over the bilateral IFG, a NIRSport 88 system from NIRx Medical Technologies (Glen Head, NY) consisting of 8 photo-detectors and 8 light emitters resulting in a total of 20 channels was used. The sampling rate was set to 7.81 Hz and the distance between the optodes was 3 cm. Both

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subjects performed four NF training sessions within two weeks. The task was to increase deoxy-Hb over the bilateral IFG [27, 30] while receiving visual real-time feedback (color changes over the bilateral IFG area depicted on a three-dimensional head model) of relative concentration changes in deoxy-Hb over the bilateral IFG when imagining swallowing movements (imagining how it feels to swallow saliva). In each NF training session, 20 feedback trials were performed (each trial lasted 17-23 s). Pause intervals were presented between the feedback trials with a duration of 30 s.

Pre-post assessment: Before and after the NF training, brain activation patterns elicited by executing swallowing movements (swallowing saliva) were assessed offline (no real-time feedback was provided). Participants performed 10 execution trials with a duration of 15 seconds. Between the motor execution trials, a variable pause of 28-32 seconds was presented.

NIRS data analysis: Relative concentration changes in deoxy-Hb during NF training were analyzed as well as changes in oxy- and deoxy-Hb during the offline measurements (pre-post assessment while executing swallowing movements). Data preprocessing included an artifact correction (visual inspection by a trained expert in NIRS data analysis), band-pass filtering (0.01 Hz high-pass filter, 0.90 Hz low-pass filter), and baseline correction (5 s baseline interval prior to task-onset, seconds -5 to 0). The NIRS signal change was averaged task-related.

For statistical analysis of the NF training data, the 20 feedback trials per session were divided in five blocks (B1 – B5) á four trials: the NIRS signal of the first four feedback trials (trial 1-4: B1), trial number 5-8 (B2), trials 9-12 (B3), trials 13-16 (B4), and the last four trials (trial 17-20: B5) were averaged, respectively. For statistical comparisons, the NIRS signal was averaged for the time interval 5-10 s after task onset (NF task). To analyze changes in deoxy-Hb over the NF training course, regression analyses were performed (predictor variable = block number B1-B5; dependent variable= average of deoxy-Hb for second 5-10 after start of the NF task). The NIRS signal of the left IFG and right IFG was used for statistical analysis.

RESULTS

Both subjects were able to linearly increase deoxy-Hb over the right IFG, while deoxy-Hb over the left IFG did not change significantly during NF training (Fig. 1).
During the offline pre-assessment, the stroke patient showed a stronger NIRS signal change when executing swallowing movements over the right IFG (affected hemisphere) compared to the left IFG, while the healthy control subject showed a bilateral activation pattern over the IFG during the execution task (Fig. 2). After the NF training, both subjects showed a bilateral NIRS activation pattern during active swallowing (Fig. 2).

Figure 1: Neurofeedback performance of the stroke patient (upper panel) and the healthy control subject (lower panel). Depicted are changes in deoxy-Hb over the five blocks (B1-B5) within one training session averaged across all 4 NF training sessions and the results of the regression analysis.

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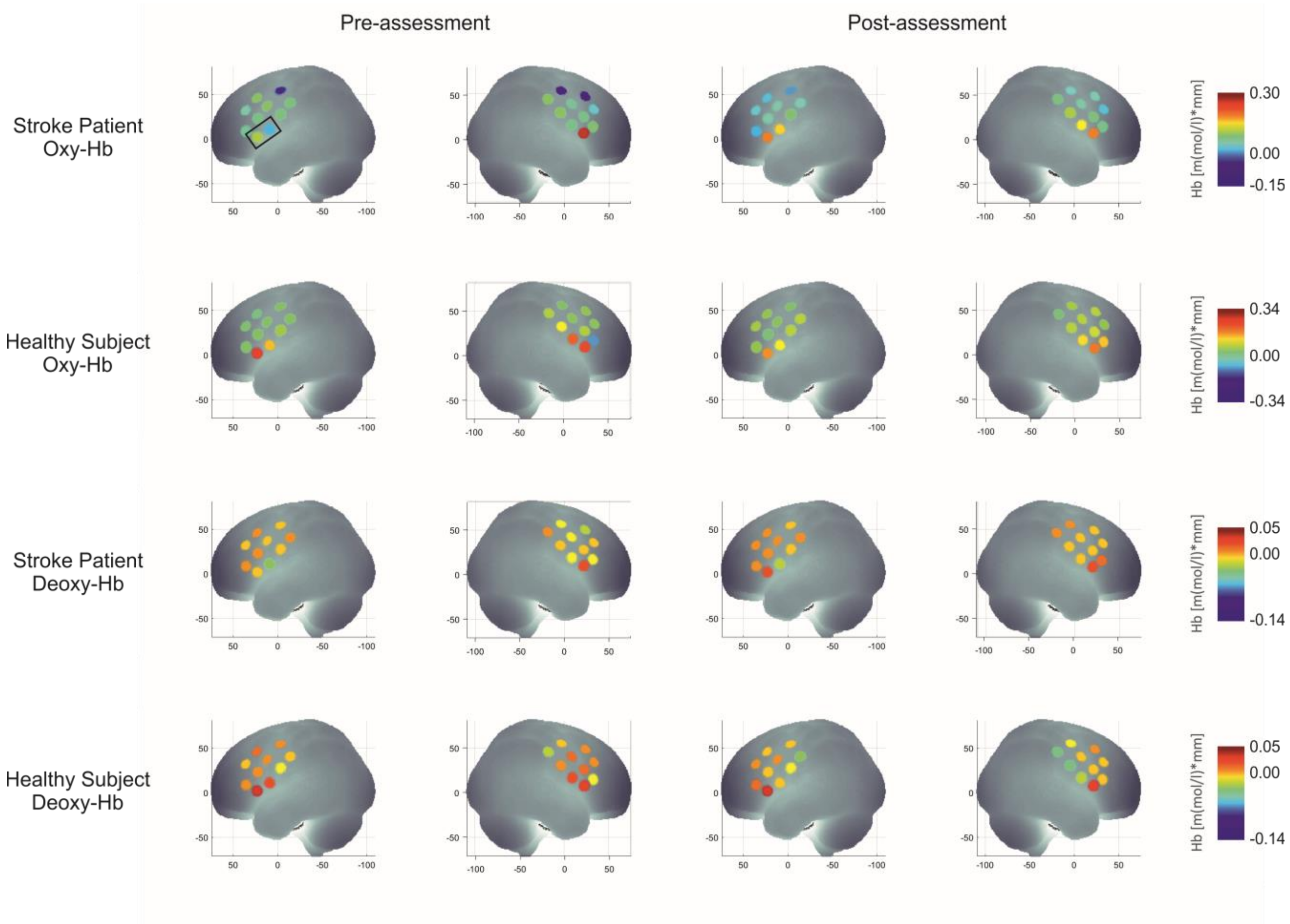

Figure 2: Activation patterns during the motor execution offline task. Oxy- and deoxy-Hb is depicted separately for the stroke patient and the healthy control subject for the 20 NIRS channels. The IFG is marked with a black rectangle in the upper left picture.

DISCUSSION

Here we showed that a stroke patient with dysphagia is able to modulate voluntarily the hemodynamic response in the swallowing motor cortex by imagining swallowing movements and that this NF training leads to neuronal plasticity processes in the swallowing motor cortex after stroke.

A stroke patient with dysphagia and a healthy control subject were able to increase deoxy-Hb linearly during NF training. This indicates that stroke patients with multiple brain lesions can learn to modulate voluntarily activity in the swallowing motor cortex when imagining swallowing movements. Our results are in line with prior findings of NIRS-based NF training studies in healthy young adults [27, 30]. Kober et al. (2018) used the same NIRS-based NF training paradigm as in the present study [30]. In this prior study, healthy young adults (mean age between 23-27 years) trained to modulate the NIRS signal in a desired direction by imagining swallowing movements. One group of healthy young adults also trained to increase deoxy-Hb over the bilateral IFG, comparable to the NF paradigm of the present study. Interestingly, the healthy young adults were also able to increase deoxy-Hb linearly over the right IFG but not over the left IFG, which is in line with the present findings in a stroke patient and a healthy elderly control subject [30]. As discussed in [30], it might be that participants concentrated more on signal changes over one hemisphere when receiving visual feedback of activation changes over the left and right IFG on a three-dimensional head model simultaneously, which might have caused the observed hemisphere differences.

When executing swallowing movements, the stroke patient showed a more unilateral brain activation pattern (stronger activation of the affected right hemisphere compared to the left hemisphere) while the healthy control subject showed a more bilateral distribution of brain activity before the start of the NF training. This is in line with prior findings that dysphagia patients often show a stronger activation of the affected hemisphere during swallowing, while healthy individuals show a more bilateral activation [3, 26–28, 33–36]. After NF training, the stroke patient showed a bilateral activation of the IFG during active swallowing. This activation pattern was comparable to the brain activation pattern of the healthy control subject [26, 28]. Hamdy et al. (1996) also found that the cortical activation of dysphagia

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patients becomes more bilaterally distributed with recovery of swallowing [36]. Hence, brain activation patterns over swallowing motor areas elicited by executing swallowing movements seem to “normalize” in the stroke patient with dysphagia after NF training.

CONCLUSION

This first proof of concept study shows that a stroke patient with dysphagia can benefit from NIRS-based NF training in which motor imagery of swallowing movements is used as mental strategy to activate the swallowing motor cortex. There is evidence that external stimulation or inhibition of the swallowing motor cortex using repetitive transcranial magnetic stimulation (rTMS) leads to recovered swallowing function in dysphagia patients [3, 35, 37–39]. With NIRS-based NF, dysphagia patients might learn to increase or decrease voluntarily the activation level in specific swallowing related brain areas, without the need of external stimulation such as rTMS [28].

Our results indicate that future NF training studies with larger samples of dysphagia patients might reveal the usefulness of NF training in dysphagia rehabilitation.

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