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Original Article

Objective and Subjective Evaluation of Neurofeedback Trainings in Nonclinical Individuals

Kota SUZUKI 1), Masahiro ISHI 2), Haruo SHINODA 3)

1) Department of Developmental Disorders, National Institute of Mental Health, National Center of Neurology and Psychiatry, Japan
2) Akita Vocational Center for Persons with Disabilities, Japan
3) Department of Clinical Psychology, Faculty of Psychology, Rissho University, Japan

ABSTRACT

Neurofeedback training aims to teach self-regulation through signals derived from neural activity. In children with attention-deficit hyperactivity disorder, neurofeedback generally focuses on increasing the power of either the beta1 (15–18 Hz) or the sensory motor rhythm (12–15 Hz), while decreasing the power of other frequency bands. The purpose of this study was to evaluate the efficacy of objective and subjective measures for assessing the effects of neurofeedback training in nonclinical adults. We evaluated the effects of eight sessions of beta1 and sensory motor rhythm neurofeedback training in nonclinical adults using objective measures (i.e., event-related potential components during a flanker task) and subjective measures (i.e., Student Behavior Checklist). Sixteen adults were divided into beta1 and sensory motor rhythm training groups. An event-related potential component, N2, was enhanced at post-training compared with pre-training periods. Moreover, we observed enhanced N2 in the beta1 group, suggesting that improved attentional function influenced the N2 component. Conversely, we found no differences in the Student Behavior Checklist between the pre- and post-training periods for either group. These findings demonstrate that subjective measures were not sufficient to uncover the effects of eight neurofeedback training sessions. Thus, we suggest that objective measures, such as event-related potential components, be used to evaluate the effects of neurofeedback training.

＜Key-words＞
Neurofeedback training, attention deficit hyperactive disorder, Biofeedback

kt.suzuki@ncnp.go.jp（Kota SUZUKI; Japan）

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I. Introduction

In neurofeedback (NF) training, the trainee learns the self-control over certain brain activity patterns via feedback on their own neural signals, for instance, via electroencephalograms (EEGs). In previous studies, NF training has been found to solve behavioral problems (Lubar, Swartwood, Swartwood, et al., 1995) and improve mental state (Gruzelier, 2014), and symptoms of epilepsy (Sterman & Egner, 2006). NF training has been especially effective for solving behavioral problems in individuals with attention-deficit hyperactive disorder (ADHD) (Gevensleben, Albrecht, Schlamp, et al., 2009; Lubar, Swartwood, Swartwood, et al., 1995; Wangler Gevensleben, Albrecht, et al., 2011).

ADHD is characterized by persistent symptoms, which include inattention, hyperactivity, and impulsivity (American Psychiatric Association, 2013). Comparing with children with typical development, children with ADHD exhibit low EEG beta (and alpha) activity (Barry, Clarke & Johnstone, 2003). Thus, one of the NF methods for treating children with ADHD aims to enhance beta activities (Gevensleben, Albrecht, Schlamp, et al., 2009; Wangler Gevensleben, Albrecht, et al., 2011). There are two types of beta-focused NF training by frequency band: sensory motor rhythm (SMR: 12–15 Hz) training and beta1 (15–18 Hz) training (Monastra, Lynn, Linden, et al., 2005). Egner & Gruzelier (2004) reported that SMR and beta1 training had different positive effects on behavioral problems: beta1 training targeted inattention, whereas SMR training targeted impulsivity/hyperactivity.

ADHD is considered as a dimension rather than a category. Nonclinical individuals who have some problems related to ADHD symptoms cannot be on medication. Thus, it is expected that application of NF trainings will be one of ways for nonclinical individuals. Feedback of improvement by NF training is important for motivating to participate in NF training. Evaluation of improvement by NF training in children with ADHD often involve assessments by caregivers (e.g., parent-rated questionnaires) (Linden, Habib & Radojevic, 1996; Lubar, Swartwood, Swartwood, et al., 1995), whereas nonclinical adults often do not have a close relationship with another adult who can conduct an evaluation. Thus, we considered that a subjective assessment via a self-rated questionnaire might be useful for evaluating NF training in nonclinical adults. In addition, we considered that objective measures such as behavioral and electrophysiological indexes were also useful, because assessment by another adult were not demanded. In this study, we examined whether assessments with objective and subjective measures uncovered the effects of beta1 and SMR training in nonclinical adults.

II. Methods

1. Participants

Eighteen adults were assigned to SMR and beta1 groups. Two participants left the study prior to completion because they were too busy with college. They reported to have no history of neurological and/or psychiatric disorder. The two groups were matched according to age and sex (three male and five female participants, SMR: 23.38 ± 2.39 years, beta1: 24.63 ± 5.45 years).

2. Protocol

This study comprised eight NF training sessions (SMR or beta1) based on previous studies (Egner & Gruzelier, 2004), and pre- and post-training assessments. Participants attended one or two sessions per week. Pre- and post-training assessments were conducted within 1 week before the start and after the end of the NF sessions.

3. NF training

NF training sessions were conducted using ProComp Infiniti (Thought Technology Inc., Montreal, QC, Canada). During the sessions, EEG was recorded from Cz with the left and right earlobes as reference and ground channels, respectively. We asked participants to increase the power of a given frequency band (SMR: 12–15 Hz or Beta1: 15–18 Hz) and to decrease the theta (4–7 Hz) and high beta (22–30 Hz) bands. The participants performed three tasks in a session. For all three tasks, the amplitude of each frequency band was represented online as a bar that changed in size. Task-specific audio-visual feedback was given in all three tasks (i.e., types of pictures, size of a movie clip, and movement of a boat game; EEG Suite, Thought Technology Inc., Montreal, QC, Canada). The three tasks took approximately 15 min to complete.

4. Pre- and Post-assessment

1) Objective measure

As an objective measure, we administered a flanker task during EEG recording. In the flanker task (Eriksen & Eriksen, 1979), stimuli of five arrows are classified into compatible stimuli (i.e., <<<<< and >>>>>) or incompatible stimuli (i.e., >><>> and <<><<) according to the relationship between the central arrow and the surrounding arrows. The participants were required to use their thumb to press a button corresponding to the direction of the central arrow. Each stimulus was presented on a PC monitor for 100 ms and the stimulus onset asynchrony was set between 2000 and 2500 ms (step = 100 ms). Left and right responses were equally required in a block. Twenty-four compatible stimuli and 36 incompatible stimuli were randomly assigned into a block, and there were 16 blocks in each assessment. The task was performed using STIM2 software (NeuroScan Inc., Victoria, Australia).

EEG and electrooculograms (EOGs) were recorded from 29 scalp electrodes (Fz, FCz, Cz, CPz, Pz, Fp1, Fp2, F7, F3, F4, F8, FC5, FC1, FC2, FC6, T7, C3, C4, T8, CP5, CP1, CP2, CP6, P7, P3, P4, P8, O1, O2), as well as at positions above and below the left eye, and at the outer canthi of both eyes, using easycaps (EASYCAP Inc., Woerthsee-Etterschlag, Germany) and NUAMPS (NeuroScan Inc., Victoria, Australia). We used the average of the left and right earlobes as a recording reference, and AFz was set as the ground electrode. The data were sampled at 500 Hz (0.1–80 Hz band-pass filtered). The electrode impedance was less than 5 KΩ. EEG signals were low-pass filtered offline at 50 Hz. EEGs were segmented into stimulus-locked epochs (i.e., −100 to 1000 ms triggered by the stimulus onset) and response-locked epochs (i.e., ±600 ms triggered by the button press). Stimulus-locked epochs were baseline corrected using the period 100-ms pre-stimulus, and response-locked epochs were baseline-corrected using the period 200-ms pre-stimulus. Gratton's ocular collection was applied to the epochs (Gratton, Coles & Donchin, 1983), and epochs containing ±50 μV were automatically rejected. We separately averaged the epochs according to compatibility (compatible and incompatible) and correctness (correct and incorrect), and had the event-related potentials (ERPs) re-referenced to the common average reference. We evaluated the stimulus-locked ERPs in trials which participants correctly responded to and the response-locked ERPs in trials that contain incompatible stimuli. The ERP analyses were conducted using MATLAB R2013b and EEGLAB v13.5.4b (Delorme & Makeig, 2004).

Behavioral measures (i.e., correct response times: correct RTs and incorrect response rates) and ERP components (N2, P3, and error-related negativity: ERN) were used for statistical analysis (Wild-Wall, Oades, Schmidt-Wessels, et al., 2009). For the stimulus-locked ERPs, N2 was identified as the negative peak between 200 and 350 ms at Fz, and P3 was identified as the positive peak between 200 and 500 ms at Pz. For the response-locked ERPs, ERN was identified as the negative peak during the period 200 ms after a response was made.

2) Subjective measure

We used the Student Behavior Checklist (SBC) as a subjective measure (Davis, Cheung, Takahashi, et al., 2011). The SBC is a self-rated questionnaire that comprises 18 items based on ADHD symptoms, as outlined in the DSM-5. According to a previous study, the two-factor model with inattention (nine items) and impulsivity/hyperactivity (nine items) as factors was an acceptable fit for Japanese and American university students (Davis, Cheung, Takahashi, et al., 2011). We used the sum of the items in each factor for statistical analyses.

III. Results

1. Behavioral measures

Table 1 shows the mean correct RTs and incorrect response rates for the compatible and incompatible stimuli at the pre- and post-training measurements in both groups. We performed analyses of variance (ANOVAs) on the correct RTs and incorrect response rates with group (beta1 and SMR), period (pre-training and post-training), and compatibility (compatible and incompatible) as factors. We found significant main effects of compatibility on both correct RTs ($F(1,14) = 77.45$, $p = .000$) and incorrect response rates ($F(1,14) = 56.01$, $p = .000$), indicating that incompatible stimuli produced longer correct RTs and higher incorrect response rates compared with compatible stimuli. We did not find any significant main effects or interactions with respect to the behavioral measures ($p > .05$).

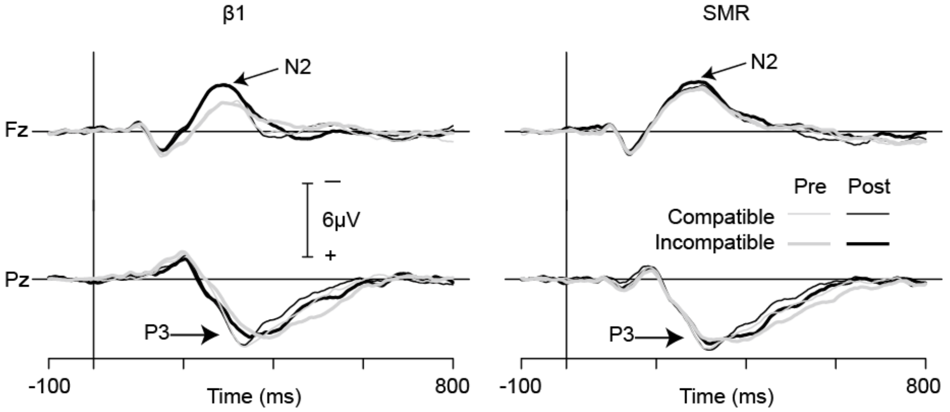
<Table 1>Means (SDs) of correct response time and incorrect response rates.

		Compatible		Incompatible	
		Pre	Post	Pre	Post
Correct response time (ms)	β1	334.05 (23.20)	343.12 (22.34)	374.99 (21.35)	383.64 (32.49)
	SMR	322.34 (22.11)	317.73 (17.62)	368.46 (41.25)	363.75 (42.55)
Incorrect response rate (%)	β1	1.68 (1.35)	1.57 (0.63)	13.88 (8.46)	11.99 (4.94)
	SMR	1.94 (2.36)	2.13 (1.69)	11.07 (8.11)	12.67 (7.84)

2. ERP components

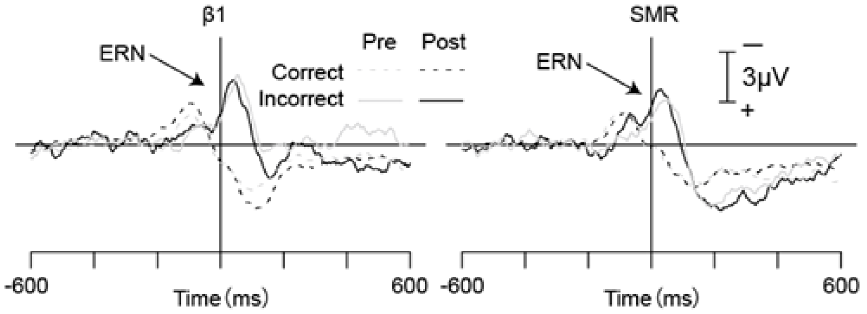
Figure 1 shows pre- and post-training grand average stimulus-locked ERP waveforms at Fz and Pz for compatible and incompatible stimuli in both groups. We performed ANOVAs with group, period, and compatibility as factors on the N2 and P3 amplitudes and latencies. We found a significant main effect of period on N2 amplitude ($F(1,14) = 5.17$, $p = .04$), indicating that post-training N2 amplitudes were larger compared with pre-training amplitudes. We could not find any other main effects or interactions with respect to N2 amplitudes and latencies ($p > .10$). Regarding P3, we found a significant main effect of compatibility on P3 latencies ($F(1,14) = 10.85$, $p = .005$), indicating P3 latencies were longer for incompatible stimuli than compatible stimuli. We could not find any other significant main effects or interactions ($p > .10$).

A visual inspection revealed a change in N2 in the beta1 group compared with the SMR group, although the interaction between group and period was not statistically significant. We conducted ANOVAs with compatibility and period as factors for each group. We found a significant main effect of period in the beta1 group (F(1,7) = 7.27, p = .03), whereas the main effect of period was not significant in the SMR group (F(1,7) = 0.64, p = .45). Thus, the observed change in N2 appeared to be restricted to the beta1 group.



<Figure 1> Grand average stimulus-locked event-related brain potential waveforms on Fz and Pz.

Figure 2 shows pre- and post-training grand average response-locked ERP waveforms at FCz for correct and incorrect responses in both groups. The negative ERP component (i.e., ERN) was enhanced during the 100 ms after incorrect responses only. We performed an ANOVA for ERN amplitude with group and period as factors for incorrect responses. We did not find any significant main effects or an interaction (p > .10).



<Figure 2> Grand average response-locked event-related potential waveforms on FCz.

3. Subjective assessment

Table 1 shows the mean scores of inattention and hyperactivity/impulsivity at the pre- and post-training periods in the SMR and beta1 groups. We did not observe any differences in inattention or hyperactivity/impulsivity scores between the pre- and post-training periods in either group. This observation was statistically confirmed by an ANOVA with group and period as factors, which did not reveal any significant main effects or an interaction (p > .10).

<Table 2> Mean scores (SDs) on the Student Behavior Checklist (SBC).

	Inattention		Hyperactivity/ impulsivity	
	Pre	Post	Pre	Post
β1	6.88	6.75	5.88	5.63
	(4.62)	(5.12)	(5.35)	(5.29)
SMR	11.13	9.88	5.88	6.00
	(5.95)	(5.88)	(5.82)	(5.89)

IV. Discussion

We used objective and subjective measures to examine the effects of NF training in nonclinical adults. With regard to objective measures, N2 was clearly enhanced at the post-training compared with the pre-training period in the beta1 group. In the flanker task, the N2 amplitude is known to represent the degree to which cognitive control is needed, e.g., the degree of conflict (Yeung, Botvinick & Cohen, 2004). However, we did not find a significant interaction between period and compatibility. Thus, the observed enhancement of the N2 after NF training might not be related to cognitive control. Egner & Gruzelier (2004) suggested that beta1 training improves attentional skills. Thus, it is possible that the information processing associated with the N2 was enhanced by improved attentional ability. As in a previous study (Egner & Gruzelier, 2004), we were able to use an objective measure to define the effects of NF training on attentional ability in adults.

When we used subjective measures, we did not find any effects of NF training in adults (i.e., each factor of SBC). It is possible that eight NF training sessions were insufficient to produce an effect. In addition, our participants did not have complaints about ADHD symptoms. Thus, participants may not have noticed improvements related to NF training. Awareness about the effect of NF training might motivate individuals to participate in NF training. Therefore, we suggest that objective assessments be administered quickly after training, and that trainers inform trainees of the results of the assessment.

Although our measures did not reveal a clear effect of SMR training, beta1 and SMR training have been found to differently improve behaviors associated with ADHD symptoms (Egner & Gruzelier, 2004), SMR training has also been found to have a positive effect on mood (Gruzelier, 2014). Thus, our measures may not have captured the effects of SMR training. A larger study sample with a greater number of NF sessions may help to resolve this issue.

This study has several limitations. Firstly, our sample size was small, which reduced statistical powers. Next, in visual inspection (Figure 1), N2 amplitudes of the pre-training period were larger in SMR than beta1 groups, although the difference was not statistically significant. It was possible that some of SMR group had sufficiently large N2 amplitudes; thus, their N2 might be not enhanced by the SMR training. Finally, in the start of this study, we expected that the improvements of some indexes were observed in only beta1 group and the improvements of other indexes were observed in only SMR group. If the expected results had been obtained, we could have used one group as control group to interpret the effects of the other group. However, we could not find the significant interaction on N2 amplitude between group and period. Thus, our results did not fully negate the practice and placebo effects on N2 amplitudes. Future studies will need to confirm our results using the control group. Typically, the placebo effect is considered to be stronger on subjective measures than objective measures. Although the practice effect is also associated with behavioral data and other ERP components, these measures were not different between the pre- and post-training periods. Therefore, we believed that there is a possibility that the difference of N2 amplitude between pre- and post-trainings was associated with the effect of the beta1 training.

In summary, we examined the efficacy of objective and subjective measures in assessing the effect of NF training on nonclinical adults. Although NF training changed our objective measure, we found no differences in subjective measures between the pre- and post-training periods. These results may indicate the possibility that objective measures more sensitively capture the effects of a small number of NF training sessions on attentional skills than subjective measures. Thus, we suggest that assessments with objective measures be conducted shortly after NF training. This may draw more attention to subtle improvements and increase motivation to participate in NF training.

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Faculty of Education, University of the Ryukyus, 1 Senbaru, Nishihara, Nakagami, Okinawa, Japan
FAX: +81-098-895-8420 E-mail: ashs201091@gmail.com

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