The effect of neurofeedback training on sleep and mood

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Abstract

Background: Neurofeedback is an intervention that enables users to perceive their own cortical activity and enables them to change it. It has been extensively studied in relation to sleep, while there is a lack of research linking it to mood. This study examines, if the usage of a portable SMR-up neurofeedback device can improve sleep and mood in the short and long-term. **Method:** 44 participants were divided into three groups. The two experimental groups received either training to stimulate beta-waves down, or regulate sensorimotor rhythm waves (SMR) up, while the control group got random neurofeedback. They were assessed with several sleep and mood measurements after the training had concluded and in the months afterward. **Results:** The SMR-up group showed improvements on all sleep measurements post-training and at some of the follow-ups, while the other groups only affected some of the sleep measurements. The only mood variable positively influenced by the SMR-up training was stress. **Discussion:** Although the study had some limitations it could replicate the positive results from previous studies, concerning the enhancing effect of SMR-up training on sleep. The results even indicated that the effect might be sustained for a longer period. Another point of interest that warrants further research is the alleviating effect on stress. Therefore, the concept of a mobile SMR-up neurofeedback device should be further explored due to its beneficial effects on sleep and mood.

Keywords: neurofeedback, sensorimotor rhythm, Pittsburgh sleep quality inventory, fatigue assessment scale, insomnia severity index

1. Introduction

1.1. The application of neurofeedback in a non-clinical setting

"What I love about neurofeedback is it is training the brain to self-regulate at the source of the problem…the brain" wrote Russell-Chapin (2016), a counselor as well as professor for brain research, in an article published in Psychology Today. This quote shows that neurofeedback has received noteworthy recognition within the scientific community in recent times. However, it has been already been around for decades. In the late 1960s, the notion that conditioning one's brainwave sequences to influence physiological functioning was possible gained the attention of various researchers. Early research focused on managing epilepsy and even increasing relaxation by the means of this novel approach (Hammond, 2007). This type of training has been named EEG biofeedback or neurofeedback. To conduct a session, electrodes are positioned on the scalp and typically also on the earlobes of the participants. Through a visual or auditive medium feedback is presented which is meant to affect the brain waves of the participants. In an ordinary setting, we do not have the awareness that would allow us to have that type of influence on our cortical activity. Neurofeedback, however, empowers the user to have that type of control by allowing the perception of brainwaves shortly after they arise. In the beginning, the results are only visible in the short term, but with the increasing progression of the treatment, the effects become more lasting. Neurofeedback training has been studied in relation to various variables. However, two variables could be especially of interest for further neurofeedback studies, because of their relevance for everyday functioning: Sleep and Mood. Sleep, on the one hand, is necessary for a variety of cognitive functions like memory, problem-solving and creativity, among others (Paller, Creery & Schechtman, 2020). This makes it highly important for everyday functioning. For example, Bjelajac, Holzinger, Lučanin, Delate, and Lučanin (2020) found that daytime sleepiness, an indicator for decreased sleep quality, can be associated with limitations in activities of daily life as well as a poor health status in a non-clinical sample. However, close to 50% among older adults indicate that they experience sleeping difficulties in some form regularly (Neilkrug & Ancoli-Israel, 2010). Consequently, sleep difficulties are a widespread issue that considerably influences our ability to operate every day. Mood, on the other hand, is another variable that should be studied in relation to neurofeedback. Gruzelier (2014), for instance, showed in a literature review, that different types of neurofeedback significantly influence mood. According to Amado-Boccara, Donnet, and Olié (1993) mood can be defined "….as a group of persisting feelings associated with evaluative and cognitive states which influence all the future evaluations, feelings, and actions". Furthermore, it is an intriguing variable to study, since it can have a great impact on our daily functioning. Liao, Shonkoff, & Dunton (2015) for instance established that positive mood is related to increased physical activity in an everyday setting. These two variables can also be associated since sleep is to be elementary for restoring emotional reactivity and salience discrimination (Goldstein & Walker, 2014). It can be concluded that Sleep and mood are two variables of interest when investigating the possible improvements neurofeedback training can lead to.

1.2. The relation of neurofeedback to sleep and mood

Among other imaging methods, the electroencephalogram (EEG) can be used to provide neurofeedback. EEG data is collected by recording electrical signals, which are emitted through brain activation, with high conductance electrodes on the scalp. Compared to other imaging techniques the EEG has a high temporal resolution, is inexpensive, and can be done non-invasively. Consequently, it is frequently used in clinical and research settings. However, it has a low spatial resolution and is usually accompanied by a high level of noise, which makes it difficult to effectively extract the required data. The electrical activity is displayed in the form of wavelengths and different patterns of brain wave activity, indicate different states of consciousness (Kolb & Wishaw, 2009). The four standard categories of brain waves are alpha, beta, theta, and delta rhythms. While beta waves illustrate alertness and excitement, alpha waves are indicative of calmness as well as relaxation. Therefore, alpha waves were first suspected to link neurofeedback and sleep. Hans Berger, the scientist who discovered them, reported that they prominently occur, during relaxed, eyes-closed periods. Therefore, they were suspected to improve sleeping patterns if they are stimulated through neurofeedback. Some researchers linked them to stress, like Tyson (1987) who showed that college students showed a decrease in the power of alpha waves after solving a stressful task, but no reliable connection to sleep was found. In a modern approach, Schabus et al. (2014) used Sensorimotor rhythm (SMR) frequencies as part of neurofeedback training to affect sleep. While alpha waves cover a frequency from 8 – 12 Hz, SMR activity ranges from 12 – 15 Hz. Schabus et al. (2014) showed that ten sessions of SMR-up feedback training led to a significant decrease in awakenings as well as slow-wave sleep, improved subjective sleep quality, and could even be related to enhanced memory consolidation in a sample of subclinical insomnia patients. Therefore, SMR could be the ideal frequency to stimulate during neurofeedback training in a study concerning its effect on sleep and there is some evidence that indicates its positive effect on sleep quality. However, this study relied on a single-blind design and did not include follow-up assessments, which limited its external validity. In the current study, Schabus et al. (2017) assessed if this outcome could be replicated with a double-blind placebo design and follow-up measurement points. Additionally, the researcher added a second control group, which included healthy controls that also received SMR-up neurofeedback just like the insomnia patients in the experimental group. Even though the sleep quality of the participants improved, there was no difference in effect between the group that received SMR-up feedback and the group the only worked with placebo feedback. Consequently, the researcher could not attribute a significant improvement in sleep to neurofeedback training. Thus, there is mixed evidence concerning the effectiveness of neurofeedback training to improve sleep quality. Furthermore, mood and neurofeedback have been extensively linked through visual fMRI feedback. Mehler et al. (2018), for instance, showed that fMRI feedback training of brain areas that are active during emotional appraisal decreased symptoms of depression in a clinical sample. Though, evidence that SMR-up training and mood are related is scarce. One study found that SMR-up training led to an increase in signs of calmness immediately after training (Gruzelier, 2014), but it has not been linked to negative indicators of mood, like symptoms of depression, anxiety, or stress. Therefore, there is a lack of research when it comes to SMR-up neurofeedback and negative manifestations of mood.

1.3. Hypothesis concerning the effect of SMR neurofeedback training on sleep and mood

Can neurofeedback training improve self-reported measures of sleep as well as mood? This study aims to investigate this question. As previously mentioned, there have been studies that explored the effect of neurofeedback on sleep, which identified that SMR waves are ideal to explore the link between the two variables (Schabus et al., 2014). However, follow-up studies have produced contrasting results (Schabus et al., 2017). This study aims at elaborating more on this association. Based on the evidence collected by the earlier study of Schabus et al. (2014) it is hypothesized that there is going to be an increase in sleep quality measured with self-reported sleep measurements (Pittsburgh Sleep Quality Inventory, Insomnia Severity Scale, Fatigue Assessment Scale) immediately after the training. Additionally, it should be questioned how long the neurofeedback effect is present after the training has concluded. Even though there was no difference between the neurofeedback group and the placebo group in the study conducted by Schabus et al. (2017), the positive effect was maintained over 3 months after the training has been concluded. This could be seen as evidence that the feedback training has a long-lasting effect and thus it is hypothesized that a possible effect of the SMR-up training is still present at the follow-up measurements. By adding a second experimental group, which also follows a training regimen, the effectiveness of SMR-up training can be compared to the stimulation of different brain waves. For this study, a beta-down group was chosen. Beta wave activity is associated with excitement, as previously mentioned, consequently, it could be assumed that decreasing them through neurofeedback leads to more relaxation and therefore to better sleep. However, there is a lack of articles that would prove this connection. Thus, it is hypothesized that there is no improvement in sleep quality for the beta-down group, neither post-training nor at the follow-up measurement points. Furthermore, the relation between mood and neurofeedback training, especially with brain waves, has not been explored by many studies. By exploring this association, this study intends to bridge that gap. There have been studies that indicated an enhancing effect of SMR-up neurofeedback on calmness (Gruzelier, 2014). This calmness could translate to an improved mood. Therefore, the last hypothesis is that neurofeedback training leads to improved scores on the self-reported mood measurements (The Depression, Anxiety, and Stress Scale).

2. Method

2.1. Design

For the present study the data was collected in a double-blind randomized controlled trial (RCT). Two experimental groups (SMR training and beta training) and one control group (Random frequencies) were included in this experiment. Internal Committee Biomedical Experiments (ICBE) of Philips Research and the University Twente Ethics Committee approved this study.

2.2. Participants

The participants for this study were randomly distributed among the three groups and four points of measurement were chosen (Pre- and post-training as well as 2 and 6 months after the training concluded). The training procedure was divided into four phases, the advertisement, the recruitment, the meeting, and the study phase. To collect the sample for this study Facebook advertisements on the page of Philips Benelux were utilized (Advertisement phase). After the participants followed the advertisement, they got to a website that was designed to elaborate more about the study and provided an Email address that allowed the users to apply. Then every potential participant received a number. To determine if the applicants are suited for the study, they were asked to complete some questionnaires (Recruitment phase). They were several inclusion and exclusion criteria presented in Figure 2.1. (E.g., Age in between 18 and 65, Use of sleep deficiency (self) treatment). 412 people initially responded to the advertisements, but 104 people dropped out because they did not complete the questionnaires. Additional 262 applicants were declared as not eligible because they did not fit the inclusion criteria or fulfilled one or more exclusion criteria (The specific criteria are listed in Figure 2.1). The predominant reasons for exclusion were irregular working hours or the use of sleep medication. In Figure 2.2. the number of subjects excluded for specific reasons is displayed. The remaining 44 respondents were invited to meet with the researchers at the laboratory (Meeting phase). Finally, the participants were assigned through block randomization to one of the three groups: SMR-up (A), beta-down (B), or only music, which was the control group (C) (Study phase). Before the training began the beta-down group (N = 16) included two more participants than the control and SMR-up group (N = 14). Overall, there were more female participants (N = 32) in the sample than male participants (N = 12). Consequently, the gender distribution in each group was tilted towards females. In the SMR-Up group, and the control group the number of males (N = 4) and the number of females (N = 10) was the same. In the beta-down group (N = 12) there were two more females. In this study, age was recorded in the form of numbers from 1 to 10, which included a certain age span respectively. The average age in this study was 7 (M = 7.05, SD = 1.794) (46 to 50), while the lowest recorded age category was 3 (26 to 30) and the highest one was 10 (61 to 65). For the SMR-up (M = 7.17, SD = 1.83) and the beta-down (M = 7, SD = 2.1) group the average age was 7 as well. In the control group (M = 6.86, SD = 1.66) the mean age was 6 (41 to 45).

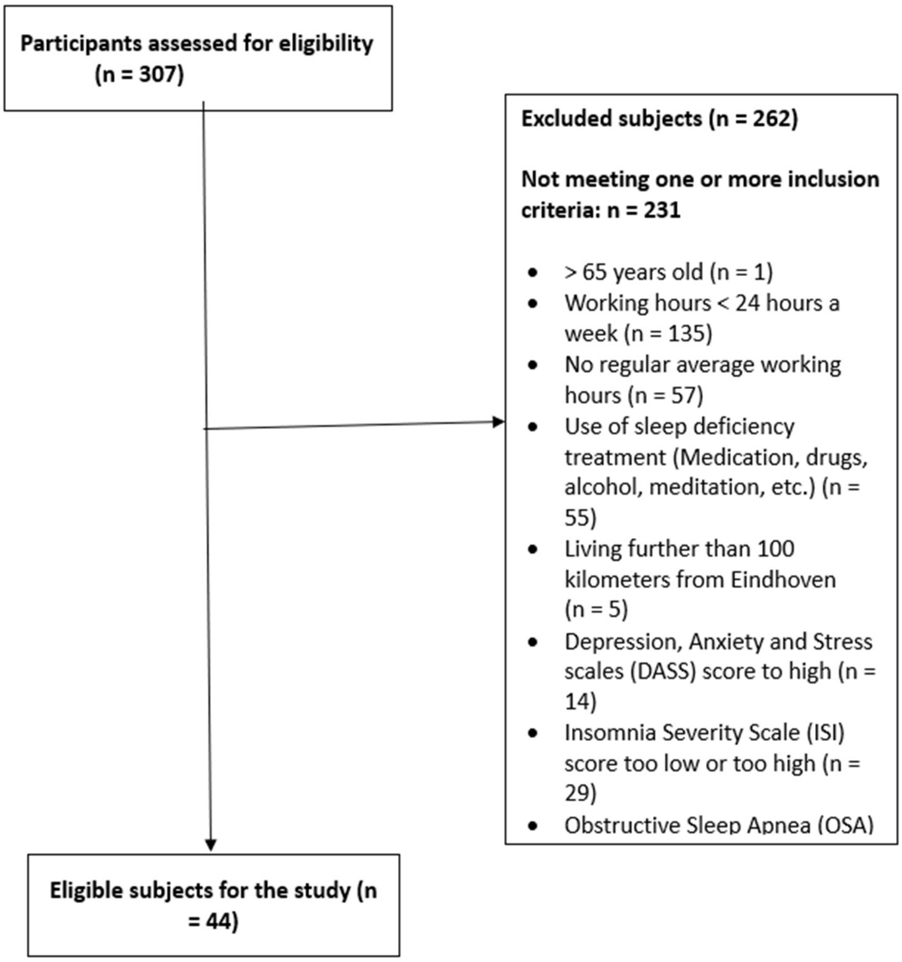
To ensure that this was a double-blind study, the participants were distributed to the different groups without the experimenters knowing about the precise placing. Also, the participants were not informed about the purpose of the different conditions. They, however, were informed about the general objective of this study.

Figure 2.1.

Schematic representation of the inclusion and exclusion criteria of this study

Inclusion criteria	Exclusion criteria
Age in between 18 and 65 years	Use of sleep deficiency (self) treatment (Medication, drugs, alcohol, meditation, etc.)
24 working hours each week	Medical conditions that affect the vestibular system (e.g., Ménière disease)
No regular working hours (E.g., 09:00 to 17:00)	Pregnancy or breastfeeding
Living in the proximity (Not more than 100 km) of Eindhoven	Being a student
Pittsburgh Sleep Quality Index (PISQI) lower than 5	Unwillingness or inability to provide informed consent
Sleep onset latency (SOL) of at least 20 minutes	Suffering from traumatic experiences
	DASS depression score > 27 (Indicative of extremely severe depression DASS anxiety score > 19 (Indicative of extremely severe anxiety) DASS stress score of > 33 (Indicates extremely severe stress)

Figure 2.2. *Flowchart of inclusion and exclusion*



2.3. Procedure

The selected participants were briefed at the laboratory in Eindhoven in groups of three to six. First, they were asked to give written consent, and afterward, they had to fill in the pre-test questionnaires. Additionally, they received their training gear and were taught how to use it. To finish the briefing, they were informed about how the training process will continue over the next

30 days, which was the average length of the study phase. During the training procedure, the activity of the different participants was observed to ensure the maintained usage of the device and to avoid missing data. In case technical difficulties occurred, the researcher would provide assistance at home and every week the participants received check-in emails to examine how the training, as well as the data collection process, is going. Additionally, there were outtake meetings that were personally conducted, for individual participants or with up to six people. In these meetings, the post-measurement questionnaires were filled out by the participants. In essence the same questionnaires from before the start of the training needed to be completed again, but there were some additional questions. The updated questionnaires included extra questions regarding how the participants experienced the training as well as the neurofeedback device. Moreover, the System Usability Scale (SUS) and the van Westendorp price sensitivity scale were added. The information obtained from the extra items was not evaluated for the present study, however, the results were assessed for internal research and development purposes. Finally, each participant that finished the training got 100 euros in the form of VVV vouchers as compensation as part of the outtake meeting. The participants that did not complete the training obtained 50 euros in VVV vouchers.

2.4. Neurofeedback training

The participants were required to complete 21 neurofeedback sessions to successfully conclude the study phase. All these sessions needed to take place at home and were conducted with the Philips audio Neurofeedback System (PNFS), which incorporated two devices. One of the subsystems was a Philips O´Neil the Stretch Headband Headset in black with five AgCI EEG electrodes, which use water as a conductor. Additionally, either a Nexus 10 or a TMSI Mobi Mini EEG data recorder was attached to the headset. The other part of the set-up was a “Samsung Galaxy Tab 2” android tablet with a playlist of the participant´s favorite music, as well as the Philips Neurofeedback application and some games.

The participants were asked to adhere to a certain structure throughout neurofeedback training. First, they were tasked to engage in the training for ten minutes, afterwards, they played games on the training device for 5 minutes, then they needed to follow the training again for 10 minutes.

The PNFS stimulated the participant by applying a first-order high pass filter (A slope of 6 dB per octave) to the music the participant was listening to. By mainly reducing low frequencies the filter decreased bass tones, which made the music less pleasant to listen to. This filter was activated when the power of the EEG band, observed in this specific experimental group, exceeded a certain threshold. Since the EEG activity is fluctuating rapidly during the time of measurement, it is difficult to adapt the music to the varying EEG signal. By breaking the EEG output down into epochs of four seconds, which include eight measurement points per second, timely feedback can be provided. At each of these measurement points, it is assessed if the measured EEG power is within the set maximum and minimum thresholds. Depending on the result, the filter is or is not applied.

To compare the effect of the SMR neurofeedback training to the stimulation of a different frequency, a beta-down group is included in this study. Moreover, Hoedlmoser et al. (2008) suggested a design in which the EEG band of interest is contrasted with a control group that receives frequencies that are not used in the experimental group. Consequently, the researcher could see if the training of the specific EEG band results in improvement. Ergo the groups analyzed in this study are:

2.4.1 SMR-up.

This group was concerned with the frequency band of 12-15 Hz, namely sensorimotor rhythm. Since the activity in this band is supposed to be stimulated for participants of this group, the filter is applied when the SMR activity is low. Consequently, low SMR activity leads to a less enjoyable listening experience.

2.4.2 Beta-down

The frequency band 15 to 30 Hz is observed in the beta-wave frequency group. To regulate the beta activity down, the high pass filter is activated in case the beta activity increases across the threshold. Therefore, the high beta activity would make the music less appealing for the participants.

2.4.3 Control

In this group, the participants would get neurofeedback, which was not based on their brain activity. To achieve this, the cut-off frequency during their training sessions would fluctuate based on pre-recorded EEG recordings. Consequently, their neurofeedback training could be considered as “random”.

2.5. Pre-and post-test measures

The pre- and post-measurements were:

- The Pittsburgh Sleep Quality Inventory (PSQI)
- The Insomnia Severity Index (ISI)
- The Fatigue Assessment Scale (FAS)
- The Depression Anxiety and Stress Scale (DASS)

The sleep quality of the participants was evaluated with the Pittsburgh Sleep Quality Inventory (PSQI) (Buysse et al., 1989). This paper-pencil questionnaire includes 19 items, but there are 5 additional items, which are supposed to be completed by a partner or a roommate, but only the self-report items are part of the final score. To assess sleep quality comprehensively, the items of the PSQI are divided into the following subcategories: Subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. Questions of different subcategories have different answer options. Items concerning sleep duration, sleep onset latency, and sleep efficiency are fill-in-the-blank questions (During the past month, how long (in minutes) had it usually takes you to fall asleep each night), while items regarding sleep disturbances, the use of sleep medication and daytime dysfunction are in a multiple option format (0=” Not during the past month”, 4=” Three or more times a week”). Every item receives a score ranging from 0 to 3. Then, based on the item scores, the component scores are calculated. By adding up all the seven component scores, the global PSQI score is calculated, which can be from 0 to 21. Moreover, a score below 5 is reflected poor sleep quality (Backhaus, Junghanns, Broocks, Rieman, & Hohagen, 2002). The PSQUI has a high validity as well as reliability, consequently, it has been used with many different populations and in a variety of settings. Compared to the paper by Backhaus et al. (2002) ($\alpha = 0.83$) the internal consistency of the PSQI in this study is lower ($\alpha = 0.65$). This, however, could have been the result of divergences between the sample of the current study and the sample in the study performed by Backhaus et al. (2002).

Moreover, the Insomnia Severity Index (ISI) (Morin, Belleville, Bélanger, & Ivers, 2011) was applied to assess the extent of the participant´s insomnia. This assessment tool is a self-report questionnaire with 7 items. Answers on the ISI are recorded with a 5-point Likert frequency scale, with 0 meaning “None/Not at all” and 4 implying “Very”. Items describe possible insomnia experiences that might have occurred to the patients in the past two weeks. “How noticeable to others do you think your sleep problems are in terms of impairing the quality of your life?” or “How worried/distressed are you about your current sleep problem?” are examples for questions in the ISI. By summing the values on the seven items a score between 0 and 21 is calculated, this is the ISI score. A score below 15 signals moderate to severe insomnia. Morin et al., (2011) have shown that the ISI has an exceptional internal consistency as well as validity with an α of 0.90. In the current sample, the internal consistency only had an α of 0.77 which is still adequate.

Additionally, the Fatigue assessment scale (FAS) (Michielsen, De Vries, Van Heck, Van de Vijer, & Sijtsma, 2004) was used to estimate the level of fatigue. This scale is a self-report questionnaire with 10 items, which records answers through a 5-point Likert frequency scale. Possible responses range from 1, which equals “Never”, to 5, which means “Always”. Items describe different ways how fatigue can manifest itself like: “I don´t do much during the day” or “I have problems starting things”. Finally, the scores on the individual items are added up, resulting in a score between 10 and 50, the FAS score. Michielsen, De Vries, & Van Heck (2003) determined that a score lower than 22 implies substantial fatigue. Furthermore, they assessed the internal consistency of the FAS for the Dutch population and the results indicated an α of 0.90, which is excellent. In the present study, the internal consistency is equally as good, with an α of 0.90.

Finally, the Depression Anxiety Stress Scale (DASS) evaluated symptoms of depression, anxiety, and stress (Lovibond & Lovibond, 1995). This questionnaire contains 42 self-report items, which are answered with a 4-point Likert frequency scale. On the lower end of the scale is 0, which represents "Did not apply to me at all", while 3 is on the upper end and means "Applied to me very much, or most of the time". The items include possible symptoms of depression ("I couldn´t seem to experience any positive feeling at all"), anxiety ("I experienced breathing difficulty (e.g., excessively rapid breathing, breathlessness in the absence of physical exertion)) and stress ("I tended to overreact to situations") the examinees might have experienced in the previous weeks. To calculate the total value of the subscales, the scores of the respective questions are added up. The maximum score of each subscale is 42 and with different cut-offs for each depression (> 13), anxiety (> 9), and stress (> 18) (Lovibond & Lovibond, 1995). Each of the DASS subscales has a good internal consistency with Depression having an α of 0.96, while Anxiety and Stress possess an α of 0.89 and 0.93 respectively (Brown, Chorpita, Korotitsch, & Barlow, 1997). The DASS has a lower internal but still good consistency in the present study (Depression $\alpha = 0.90$, Anxiety $\alpha = 0.81$, Stress $\alpha = 0.91$).

2.6. Statistical analysis

The statistical analyses were performed using Statistical Package for the Social Sciences 26.0 (SPSS Inc, Chicago, IL; 34). The data was analyzed with a linear mixed model repeated measures analysis. Beforehand it was investigated if outliers and missing data were present in the current sample. No outliers were detected, but there was some missing data. Entries were missing for the ISI (N = 2), FAIS (N = 2), Depression (N = 1), Anxiety (N = 1), and Stress (N = 1) scores. However, linear mixed models can handle missing data, by substituting the absent values with estimates based on the present data. The repeated variable in this study were the different measurement points. While the fixed variables where the different measurement points and the groups the participants belong to. The various measurement tools that assessed sleep quality and mood served as dependent variables. The Insomnia Severity Index (ISI), the Fatigue Assessment Scale (FAS), and the Pittsburgh Sleep Quality Inventory (PSQI) were used to evaluate sleep quality, while the Depression, Anxiety, and Stress Scale (DASS) was applied for mood. Depression, anxiety, and stress are measured with the DASS individually. Consequently, the is a score for each of these variables. For each measurement a decreased score equals an improvement on the variable it measures.

3. Results

3.1 The effect of the neurofeedback group on sleep

The ISI score improved at the post training and the two follow-up measurements in each of the groups, as seen in table 3.1. The table also shows that each of the effects was significant. However, the effects were bigger in the SMR-up group compared to the patients that received the beta-down or control treatment, which is displayed in figure 3.1. Towards the 6 months measurement point the effect decreased for all groups but was still significant.

Table 3.1

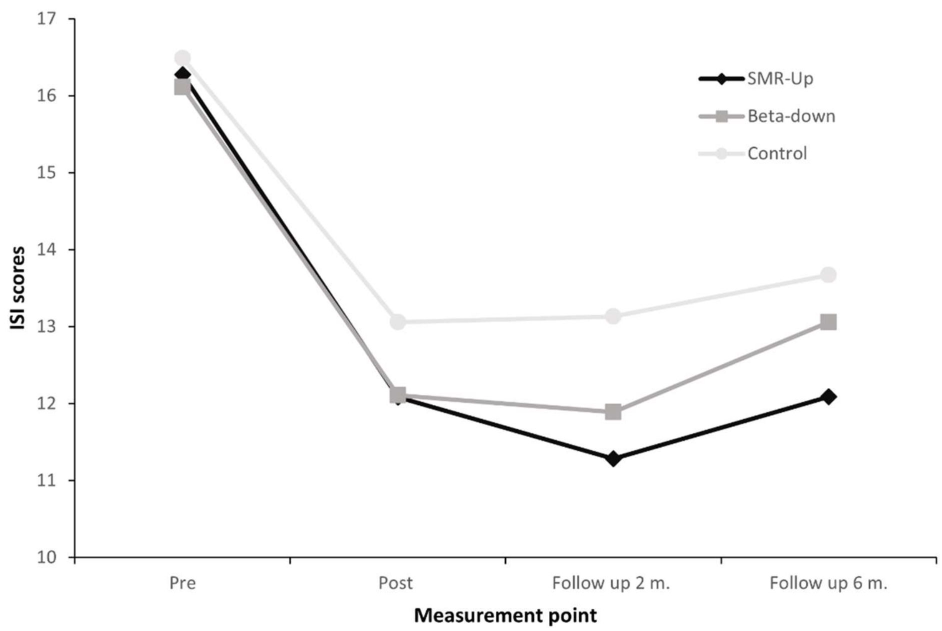
The effect of group on ISI score at different measurement points

Groups	t			Sig.		
	SMR-Up	*Beta-down*	*Control*	SMR-Up	Beta-down	Control
Pre	0[b]	-.167	.209	/	.868	.835
Post	-4.195	-4.168	-3.222	.000***	.000***	.002**
Follow-up 2 months	-4.996	-4.388	-3.146	.000***	.000***	.002**
Follow-up 6 month	-4.188	-3.220	-2.606	.000***	.002**	.011*

[b] This parameter is set to zero, because is redundant, * $p < .05$, ** $p < .01.$, *** $p < .001$

Figure 3.1

The effect of group on ISI score at different measurement points



Note. This figure illustrates the effect of the different neurofeedback training regimes on the ISI scores of the participants. The different lines stand for the different types of neurofeedback. All the effects are significant, and the SMR-up has the biggest effect at the post, 2-month and 6-month measurement point.

Table 3.2 shows that the PSQI score was significantly affected by the SMR-up training. The effect after 2 months was even higher compared post training measurement point. However, figure 3.2 indicates that the effect decreased at the 6 months follow up. Moreover, at this time point it was not significant anymore. The same applies for the participants that received the beta-down training (table 3.2), but the effect sizes were greater in the SMR-up group. Furthermore, the training of the control group did not significantly influence the PSQI score (table 3.2).

Table 3.2

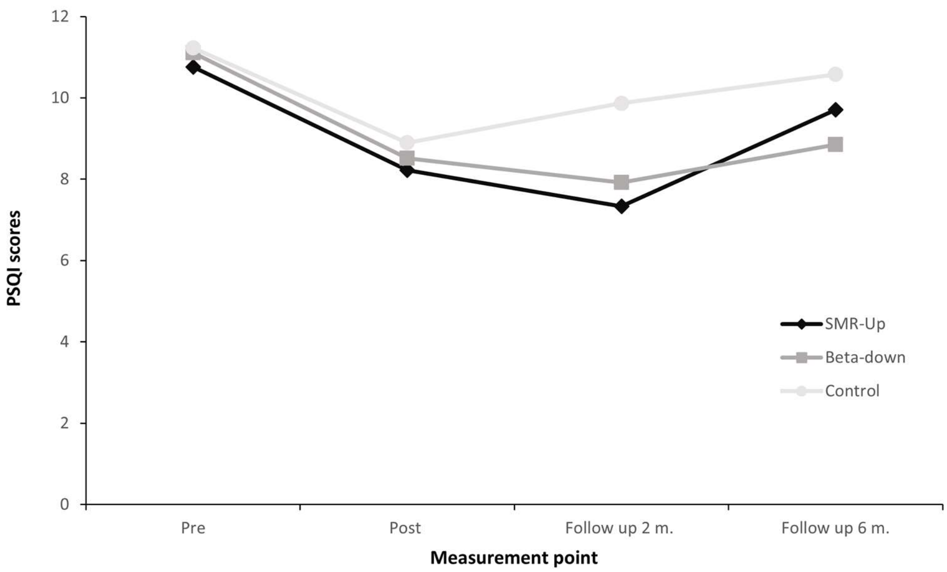
The effect of group on PSQI score at different measurement points

Groups	**t**			**Sig.**		
	SMR-Up	*Beta-down*	*Control*	*SMR-Up*	*Beta-down*	*Control*
Pre	0[b]	.357	.5	/	.357	.643
Post	-2.071	-2.33	-2	.015*	.028*	.066
Follow-up 2 months	-2.926	-3.117	-1.006	.001**	.006*	.375
Follow-up 6 month	-.993	-2.515	-.253	.298	.061	.857

[b] This parameter is set to zero, because is redundant, * $p < .05$, ** $p < .01$.

Figure 3.2

The effect of group on PSQI score at different measurement points



Note. In this graph the lines display how each training influences the PSQI score of the participants at different time points. The effect at the post training and the 2 months follow-up measurement point are significant for the SMR-up and the beta-down group. However, the effects of the SMR-up group are bigger.

Finally, the FAS score only improved for the SMR-up group. At the post training measurement point there was a significant decrease in FAS score, presented in table 3.3. As seen in figure 3.3, the effect diminished for the 2 months follow-up, but at the 6 months measurement point it increased again. While the effect was not significant 2 months after the training had concluded, it was significant 6 months afterward. The training the control and the beta-down group received showed no significant effect on FAS score at neither of the follow-up measurements (table 3.3).

Table 3.3

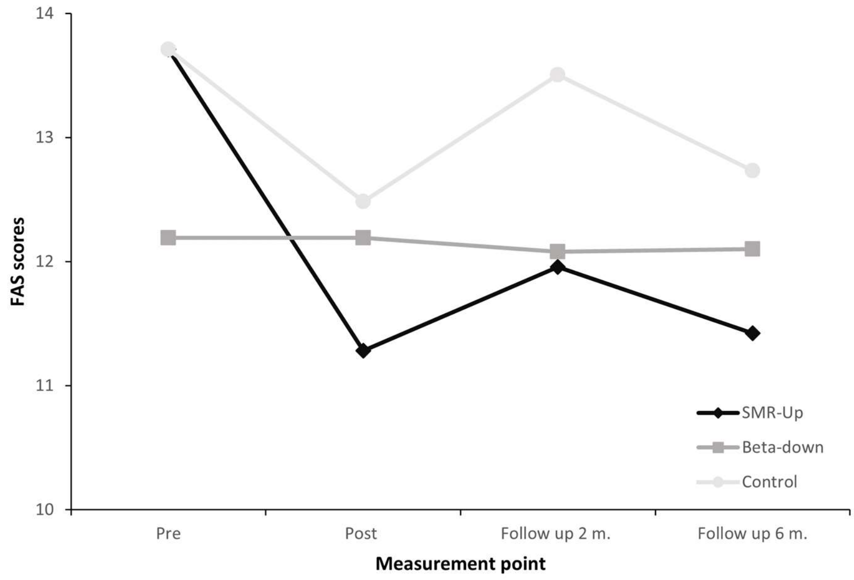
The effect of group on FAS score at different measurement points

Groups	t			Sig.		
	SMR-Up	*Beta-down*	*Control*	*SMR-Up*	*Beta-down*	*Control*
Pre	0[b]	-.190	.0	/	.85	1
Post	-2.427	-1.52	-1.228	.019*	.134	.224
Follow-up 2 months	-1.754	-1.63	-.204	.087	.108	.839
Follow-up 6 month	-2.288	-1.608	-.977	.027*	.113	.332

[b] This parameter is set to zero, because is redundant, * $p < .05$

Figure 3.4

The effect of group on FAS score at different measurement points



Note. In this figure, each line represents the FAS scores of a certain group of participants. The FAS score was only significantly affected by the SMR-up training at the post training and the 6 months follow-up measurement point.

3.2 The effect of the neurofeedback group on mood.

Neither the beta-down and the SMR-up nor the control condition had a significant effect on anxiety and depression at one of the measurement points. However, the SMR-up group displayed a lowering effect on the stress score at the post training and 6 months measurement point (table 3.4). The figure 3.4 shows that the effect decreased at the 2 months follow up, but it increases again after 6 months.

Table 3.4

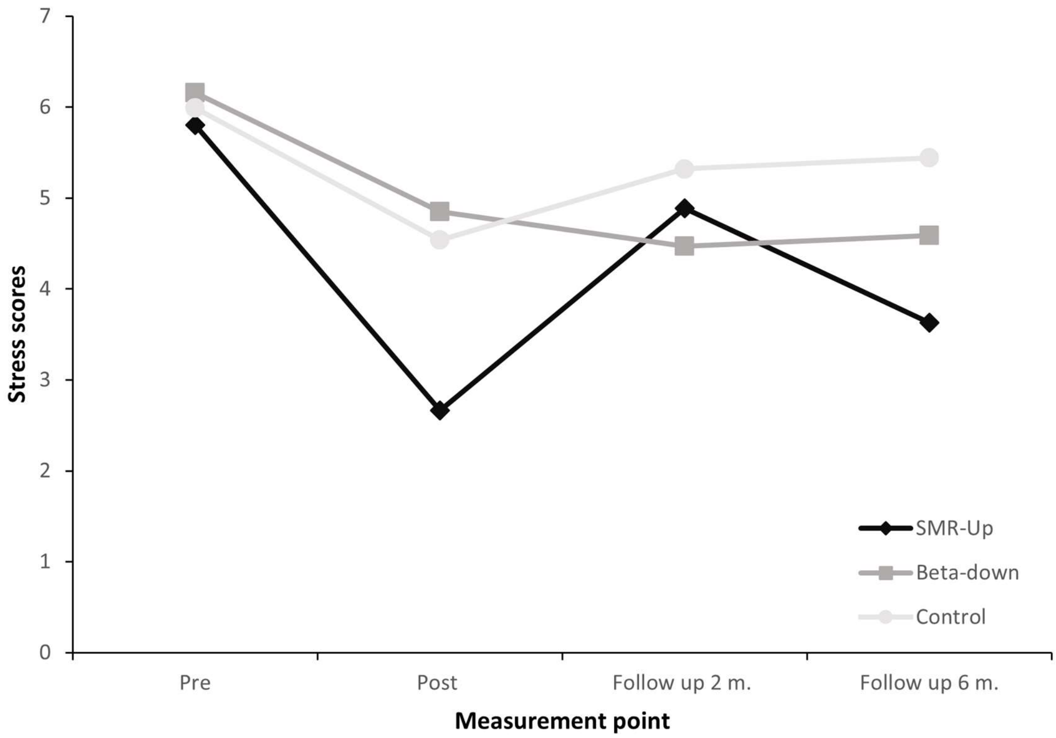
The effect of group at different measurement points on stress score

Groups	**t**			**Sig.**		
	SMR-Up	*Beta-down*	*Control*	*SMR-Up*	*Beta-down*	*Control*
Pre	0^b	.356	.184	/	.724	.855
Post	-3.138	-.955	-1.265	$.003^*$	.344	.211
Follow-up 2 months	-.917	-1.336	-.484	.365	.186	.630
Follow-up 6 month	-2.177	-1.217	-.363	$.035^*$	.229	.718

^{b} = value set to zero because it is redundant, * $p < 0.05$

Figure 3.4

Th effect of group at different measurement points on stress score



Note. The effect of the different groups on the stress score of the participants is represented by a line in this figure. Immediately after the training has finished and 6 months afterwards the effect is significant.

4. Discussion

This study explored the effect of different types of neurofeedback training on sleep and mood. All types of training led to a significant decrease in ISI score at each of the measurement points. Furthermore, the PSQI scores were significantly lower at the post-training and the 2 months follow measurement point for the SMR-up group. However, the same effect has been observed for the beta-down group. Finally, the FAS score was only significantly affected for the

SMR-up group. At the post-training measurement point and the 6 months follow-up participants in this group had a reduced score on this measurement. The positive effect of SMR-up training on the different qualitative measures of sleep was still present at one or both follow-up assessments. Concerning the effect of the neurofeedback training regime on the DASS score, neither of the regimes had a decreasing effect on the depression and anxiety subscales. However, participants that received SMR-up neurofeedback training displayed a decline in stress score immediately after the training has been completed as well as 2 months after.

The first hypothesis mentioned in the introduction of this study was, that SMR-up training improves sleep quality at a short-term level. Earlier research by Schabus et al. (2014) has supported this assumption and therefore it was expected that this effect will be replicated. It can be concluded that this hypothesis was confirmed since participants from this group showed an improvement on various self-report measurements of sleep. Moreover, the second hypothesis of this study was concerned with the longevity of the training effect. Since previous studies found, that this type of training led to a long-term improvement in sleep quality (Schabus et al., 2017), it was hypothesized that SMR-up training positively influences sleep quality at the 2 months and 6 months follow-up measurement points. This hypothesis can be partially accepted. The measurements for insomnia, fatigue, and sleep quality improved at the follow-up assessments for the participants who received SMR-up conditioning, but the results were inconsistent. While there was still an improvement in sleep quality after 2 months, which was not present anymore 4 months later, the decline in fatigue was visible at the 6 months follow-up, but not at the 2 months assessment point. Furthermore, the third hypothesis of this study was, that the group that received beta-down training, will not experience improved sleep. Since the participants in the beta-down group displayed a decrease in fatigue and insomnia after the training was finished and at some of the later assessments, this hypothesis is rejected. Additionally, even the control group, which received random neurofeedback, also showed a significant decline in insomnia. Consequently, some of the other training regimes also led to improved sleep. Finally, the last hypothesis of this study was, that SMR-up training would lead to improved mood. This hypothesis can be rejected since SMR-up training did not significantly affect depression or anxiety, two variables related to mood. However, this training specifically, resulted in a decrease in stress immediately after it was concluded and 2 months afterward. This effect was not present in participants belonging to the beta-down or the control group. This result indicates that SMR-up neurofeedback training has an alleviating effect on stress, even 2 months after the intervention has taken place.

These results build upon the existing evidence of Schabus et al. (2014). They showed that SMR-up training leads to improvement in self-reported sleep quality. This study tested this assumption with a neurofeedback set-up, that can be used in a variety of settings. On the one hand, the data suggests that SMR-up training with the portable device can lead to an enhancement of various sleep variables. On the other hand, some of the other types of neurofeedback training regimes included in this study also improved variables related to sleep. As mentioned previously, Schabus et al. (2017) encounter a similar phenomenon in their follow-up study. After replicating their first experiment with a double-blind placebo design, they discovered that placebo training, as well as SMR-up training, had a positive effect on self-reported sleep quality. Consequently, it could not be concluded if SMR-up training or the mere presence of a neurofeedback regime led to the positive development. Compared to this study, the current one has the advantage that the SMR-up training positively influenced all variables related to sleep, while the other types of neurofeedback only affected some sleep variables. Thus, the data still supports the assumption that SMR-up neurofeedback training improves variables related to sleep, even when conducted with a portable set-up. These observations have several implications on the treatment of sleep difficulties by using a mobile health device regularly. As mentioned during the introduction, nearly 50 % of the adult population experience problems with their sleep (Neilkrug & Ancoli-Israel, 2010). However, an SMR-up neurofeedback device, which can be used everywhere (E.g., On the train during the daily commute or in the living room at home), could help these individuals to better master their daily life. People from various backgrounds could benefit from a device like that. It could enhance the job performance of employees, which is even more important in professions that the population relies upon during emergencies. DuRousseau, Mindlin, Insler, & Levin (2011) for example conducted music-based neurofeedback training with a group of first responders, which lead to improved sleep quality and a decrease in insomnia. Consequently, intervention like that can improve wellness in professions with immense societal importance, which could lead to improved job performance. Moreover, SMR neurofeedback training was associated with improved sleep onset latency as well as sleep quality in ADHD patients, which usually suffer from sleep difficulties regularly (Arns, Feddema, & Kenemans, 2014). Therefore, adherence to an SMR-up neurofeedback program could support people that suffer from certain disorders. In addition to the beneficial effect on sleep, the results indicate that the applied neurofeedback training had an alleviating impact on stress. Previous research has not focused on the link between stress reduction and neurofeedback, specifically SMR-up training. Thus, the current evidence is one of the first steps in exploring this relationship. In one of the few studies that examined this association, Bennett, Lambie, Bai & Hundley (2020) found that college students which received neurofeedback therapy showed a significant decrease in perceived stress compared to students that did not. Since this study had a quasi-experimental design, its methodology might be limited. However, it also shows that neurofeedback devices, like the ones used in the current study, could be used in the future to improve stress management in populations that experience mental pressure. The portable nature of the device would make it even easier for individuals to adhere to the training. Furthermore, there is some evidence that this is a long-term effect, but as previously mentioned this evidence is mixed. Concerning the effect on sleep, the SMR-up group displayed maintenance of the positive effect at the 2 months follow-up for the insomnia and sleep quality measurements. Consequently, it can be said that the effect does not immediately diminish after the training has finished. This would allow the user to pause the treatment for a certain period if they followed the training for 30 days, which was the length used in this study. However, the data for these two measurements also points to a rapid decline of the effect at the 6 months follow-up. The same trajectory has been observed for the stress score. Thus, a continuation of the training is recommended after 2 months, to ensure maintenance of the positive effect. In contrast, the effect of the treatment on fatigue declined at the 2 months measurement point and increased again 6 months after the training concluded. Therefore, the user would profit long-term from the treatment, even though there is a dip in effectivity before that.

Although this study has many strengths, like its randomized double-blind placebo design, several follow-up measurements points, the variety of different self-report measurements used, as well as the inclusion of a control group that receives randomized neurofeedback and a second experimental group that follows a different regime, it also has some limitations. First, the small sample size should be mentioned. In each of the groups are only 14 to 16 participants. Due to the longitudinal nature of the study and the strict exclusion as well as inclusion criteria, it is difficult to get a substantial sample. However, to obtain reliable results a bigger sample size is needed.

Second, during the study, it was not assessed where the participants predominantly used the device. The portable nature of the set-up can be seen as an advantage since it makes the application easier. However, now the environment in which the training is conducted is more of a confounding factor. Some participants might have only engaged in the training while lying in bed before going to sleep, which could have caused a positive impact on sleep. Other participants may have only used the device during their commute. Conducting the training while using public transport may have led to a diminished effect. Therefore, the environment in which the device has been used in could have affected the outcome. Third, the current study was limited by its reliance on self-report measurements. Even though a wide variety of well-validated and reliable questionnaires have been applied, there is a lack of alternative measurements. Sometimes there can be a significant difference between the data collected from subjective and objective sleep measurements (Lauderdale, Knutson, Yan, Lui, and Rathouz, 2009). For this study specifically, the inclusion of physiological measures of sleep would have led to a more precise assessment. Currently, the gold standard for the physiological evaluation of sleep is polysomnography (Kushida et al., 2005). In a study comparing a self-reported sleep measurement with polysomnography assessment Westerlund, Lagerros, Kecklund, Axelson, & Åkerstedt (2014) found that the assessment of habitual sleep quality with questionnaires had high physiological validity, while both methods differed in the evaluation of restoration through sleep. Therefore, the additional evaluation with physiological measurements might have resulted in a more precise appraisal of the participant´s sleep quality. Finally, to assess the long-term effectiveness of the intervention, more follow-up measurements should be included. In the current design, 2 months after the training has been concluded the first follow-up took place, while the second one was conducted four months after that. These measurement points are placed relatively far apart, which results in missing information concerning the longevity of the effects. An additional measurement point 4 months after the conclusion of the training could be helpful to assess the effect over time. The impact of the training on the FAS score was inconsistent with the pattern seen for the other two measurements, as mentioned before. With an additional measurement point, for instance, it could be analyzed if the influence of the treatment slowly increased from follow-up to follow-up. In the current set-up, it is only visible, that the effectiveness was clearly higher after 6 months than after 2 months.

Consequently, future studies should put an emphasize collecting a bigger sample size to increase the reliability of the results. Furthermore, it would be beneficial to investigate where the participants engage in the training with the portable set-up, to explore if this variable is a confounding factor. Moreover, future studies could enhance the validity of the results by including physiological measures in the assessment. Additionally, by adding more follow-up assessments to the design prospective research could investigate the long-term effects of the training more precisely. These improvements could be applied, to enhance the design of this study. However, the current data also suggests other points of emphasis for subsequent research. Beta-down has not been explored extensively regarding sleep, but this study showed that it may have a positive effect on this variable. Thus, future research could examine the comparison between beta-down and SMR-up training as sleep-enhancing interventions. Finally, the results of this study indicate that aside from sleep, SMR-up training may have an alleviating effect on stress. Research on this topic has been scarce. Prospective studies could investigate this relationship, to broaden the area of application for SMR-up training.

In conclusion, even though there are some methodological limitations, and the results are not definitive, the current study found that a portable SMR-up set-up can be a helpful device for improving sleep as well as alleviating stress. The data even suggests that the effect maintains itself over 2 months. Since the evidence indicates, that the impact decreases after 6 months, it is recommended to refresh the training regularly. However, users can enjoy the sleep-enhancing and stress minimizing impact for an extended time, after the training concluded. This, in turn, has the potential to improve the daily functioning of many individuals.

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