A NOVEL APPROACH TO ALPHA ACTIVITY TRAINING USING WATER BASED ELECTRODES

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Abstract: Fifty healthy participants took part in a double-blind placebo-controlled study in which they were either given auditory alpha brain activity (8–12 Hz) training (N=18), random beta training (N=12), or no training at all (N=20). A novel wireless electrode system was used for training without instructions, involving water-based electrodes mounted in an audio headset. Training was applied approximately at central positions C3 and C4. Post-training measurement using a conventional full-cap EEG system revealed an increase in alpha activity at posterior sites compared to pre-training levels. This significant increase was present only in the group that received alpha training, and remained evident at a 3 month follow-up session. In an exit interview, approximately twice as many participants in the alpha training group mentioned that the training was relaxing, compared to those in the control groups. Overall, results suggest that self-guided alpha activity training using this novel system is feasible and represents a step forward in the ease of instrumental conditioning of brain rhythms.

1 INTRODUCTION

Stress and relaxation

Keeping up with the pace of modern society seems to be increasingly difficult for many people. It has been estimated that work-related stress negatively affects at least 40 million workers in 15 countries of the European Union (European Commission, Employment & Social Affairs, 1999, cited in Mental health policies and programmes in the workplace, WHO, 2005). Strategies for coping with such stress can be diverse, like getting a massage, practicing yoga, doing mindfulness training or even going into cognitive therapy. Here we initiated a program which explored whether instrumental conditioning of alpha brain activity (by neurofeedback) could help people to relax in an easy and enjoyable way at low cost.

Alpha brain activity and relaxation

The human brain rhythm in the alpha range (8-12 Hz) has been associated with reduced information processing by a decrease in cortical activity (Adrian & Matthews, 1934; Pfurtscheller, 1991) and with a relaxed state of mind (Lindsley, 1960). Previous attempts for increasing alpha activity by instrumental conditioning have been reported to increase subjective feelings of relaxation and well-being (Hardt & Kamiya, 1978; Nowlis & Kamiya, 1970; Watson, Herder & Passini, 1978; Rice, Blanchard & Purcell, 1993). Unfortunately, much of the research focusing on manipulating alpha activity has suffered from methodological difficulties such as the absence of adequate control conditions (Vernon et al., 2009).

The present approach

We wanted to investigate whether instrumental conditioning of alpha activity could be applied in a consumer product aimed at healthy everyday users. Because we wanted to create a pleasant form of training, auditory feedback was given by the person's own favourite music. Simple high-pass filtering on the music greatly affected music quality,

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which turned out to be the basis of a very intuitive form of feedback because subjects know their favourite music very well. Because of this, no instructions were needed for the participant for training to occur (self-guided training). In this way relaxation training is easy: we pictured a person sitting in the train, wearing a device similar to an MP3 player, listening to his/her own favourite music. Because listening to music might be relaxing by itself, one group in our design served as control and only listened to their favourite music. And because experiencing changes in music quality alone can already indicate that one is part of an experimental group, a second control group, which received random beta (random 4 Hz bins between 14-30 Hz) feedback, was added. Next to this strong placebo-controlled experimental design, the investigation was double-blind. Furthermore, if our device is going to be used in real-life situations, the measurement of alpha activity should be greatly simplified: conductive gel or pastes are out of the question. For this we used (tap) water-based electrodes that were, as we can show, as reliable as the conventional way. These electrodes, mounted in the auditory headset, were used as an intermediate step towards dry electrodes.

2 METHOD

2.1 Study Design

Sixty-two healthy students were randomly assigned to our three groups: alpha training (A), random beta training (B), or music only group (C). Unfortunately, twelve persons had to be excluded from our final analysis either because they failed to complete the training sessions or because of technical problems during training sessions. Eventually, 50 participants (mean age 21) were in one of the three groups: A: 6 male, 12 female; B: 3 male, 9 female; C: 5 male, 15 female. Before and after 15 training sessions on consecutive days, a quantitative electro-encephalograph (QEEG) using a Neuroscan system with 26 electrodes (according 10-10 system) was taken, together with several questionnaires. After three months, a follow up measurement took place to investigate possible long-term effects.

2.2 Training Sessions

One training session (of about 1 hour) contained two baseline measurements of 5 minutes rest with eyes open and 5 minutes rest with eyes closed. After that, 3 neurofeedback training intervals of 8 minutes were interspersed by cognitive tasks of 5 minutes each (Flanker, Stop-signal, Stroop, N-back). The purpose of this sequence was fourfold: we wanted to avoid participants falling asleep during one long relaxation session; we wanted to assess the effects of alpha training on simple cognitive tasks administered longitudinally; by alternating relaxation and cognitive work we hoped to capture details relating to the dynamics of the alpha rhythm; and it allowed us to match alpha levels to the audio filter. Every participant was asked to keep their eyes open during the neurofeedback intervals. Alpha training might be less effective during eyes closed, where alpha power is generally higher and may cause a ceiling effect in training.

2.2.1 Alpha Activity Training Tool

During training sessions each participant was seated in a comfortable chair in front of a laptop. The participants were given a set of headphones that they used for listening to their favourite music (all types of music were allowed). EEG was measured using Ag/AgCl ring electrodes, roughly positioned over C3 and C4, mounted at the inner side of the headset band. Electrodes A1 and A2, mounted in the ear covers, served as reference (C3-A1, C4-A2). Horizontal and vertical EOG was measured from electrodes at the outer canthi and above and below the left eye, respectively. The quality of the data was assessed on-line via the ratio of the power in the 49-51 Hz (noise) range, relative to the power in the 4-35 Hz (signal) range. The signals were amplified (DC-400 Hz) and sampled at a rate of 1024 Hz by a 24 bit A/D converter on a Nexus-10 portable device (MindMedia B.V., The Netherlands). The signals were transmitted via Bluetooth to a PC that controlled the experiment, and stored the data. Electromagnetic influence (EMI) was eliminated in our training via the 100 dB common-mode rejection ratio (CMRR) of our Nexus-10 device.

2.2.2 Neurofeedback Protocol

Eight times per second (each 125 ms) a segment of the preceding 4 seconds was filtered by a third-order Butterworth band-pass filter from 4-35 Hz, and a first order notch filter at 50 Hz. To be usable for a feedback update, this segment should fulfil three criteria: (i) no clipping or overflow of the amplifier; (ii) peak-to-peak of at most 200 μV; (iii) the ratio between the line noise (49-51 Hz) and EEG power (4-35 Hz) should be smaller than 1.0. For each channel (C3 and C4), the relative alpha power was calculated as the sum of the power in the alpha band

(8-12 Hz), divided by the sum of total power (4-35 Hz). A low cut-off frequency of 4 Hz was used to be relatively free of slow drift artefacts. If both channels showed a good epoch (fulfilling the 3 criteria) of 4 seconds, then the average of the two channels were used. If neither channels resulted in a good epoch, then no feedback update was given. The relative alpha measure was filtered by a first-order IIR filter with a time constant of 4 seconds to smoothen the speed of the changes in feedback somewhat. The relative alpha measure was used to drive the cut-off frequency of a first-order high-pass filter built into the audio path of the music played through the headphones. This cut-off frequency equalled 2 Hz if the current alpha level was larger than the maximum alpha level for the previous part, and 2000 Hz if the current alpha level was lower than the minimum alpha level for the previous part. For intermediate levels, a linear interpolation was done using the following formula: fc=2000–(2000-2) * (alpha-alpha_min)/(alpha_max-alpha_min), where fc= audio cutoff frequency, alpha =current alpha level, min_alpha= minimum alpha level, max_alpha= maximum alpha level. This procedure resulted in a very intuitive feedback mechanism in which a person's own well-known favourite music sounded thin and distant if alpha levels were low because the low tones were removed. When alpha levels were high the music sounded rich and full. In the random beta group, similar neurofeedback was given. Only, the EEG frequency used to drive the audio filter was always between 14 and 30 Hz. Beta bands (4 Hz) on different days did not overlap. The minimum and maximum beta levels were calculated from the first baseline (eyes open) measurement of that day in the band that was chosen for that day. In the music only group, no feedback was given. The participants always listened to their favourite music in full quality.

Importantly, all participants received no instructions about the training. They were not told that they were expected to increase the quality of the music; they were only asked to 'sit back and relax'.

2.3 Pre and Post Measurement QEEG

Alpha power spectral density was estimated using the Welch (1967) method on digitally filtered EEG. The EEG and EOG data channels were first off-line filtered with a 50 Hz first order (6 dB down per octave) notch filter for removing line noise, and then by a third-order (18 dB down per octave) Butterworth high-pass filter at 1 Hz and low-pass at 65 Hz. EEG spectra were computed and the EEG record was then segmented in 75% overlapping intervals of 4 seconds. Thus, each epoch was shifted one second forward in time, and there were 120 segments in total. Horizontal and vertical EOG channels were used to correct the EEG signal for eye movement artefacts using a linear regression method with separate coefficients for horizontal and vertical eye movements (cf. Verleger, Gasser, & Möcks, 1982). This correction was only applied if the EOG in a particular segment exceeded 60 μV. The segments were then transformed to the frequency domain using a Hanning window for tapering. The FFT power values were then transformed to a log10 scale and all frequency components (0.25 Hz resolution) were averaged to form the frequency bands Alpha (8-12 Hz) and Total Power (4-35 Hz). Relative alpha power was calculated as the ratio between alpha and total power.

2.4 Statistical Analysis

We first checked all measures for normality of the sampling distribution, and log-transformed the data if necessary. All calculations were done using (autoregressive) linear mixed models (SAS PROC MIXED 9.1), with a 0.05 level of significance. We used between-subjects factor group and within-subjects factor session (pre, post, follow-up). Using young healthy participants, instead of persons with a higher stress level, could mean that the chances of finding strong effects are not very high. On the other hand, we reasoned that such a situation constitutes a powerful test, and that finding such effects would be quite meaningful and important.

3 RESULTS

3.1 Comparison of our Water-based Electrodes with Conventional QEEG

Figure 1 shows grand average (N= 50) power spectra recorded from positions C3 and C4 with the conventional full-cap QEEG on pre-measurement and the novel system on the first training day. It shows that the systems were remarkably alike in the alpha frequency range; the difference at higher frequencies arises because of the different ways in 50 Hz line noise filtering. Alpha power (8-12 Hz) recorded with the QEEG system and with the novel system could not be distinguished statistically (QEEG versus headset: $F(1,43) = 1.67$, n.s.; Eyes open versus eyes closed: $F(1,43) = 9.87$, $p < 0.01$; C3 versus C4: $F(1,43) = 0.28$, n.s.). In addition,

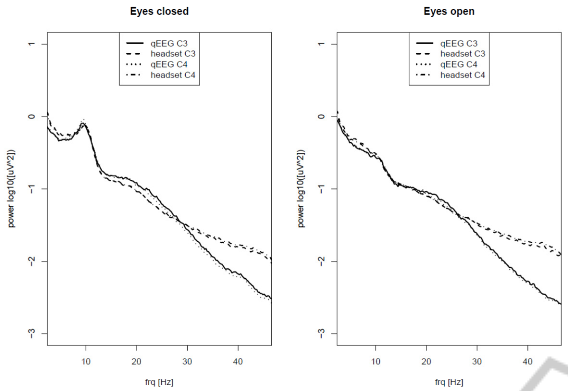

Figure 1: power spectra from our novel system and conventional QEEG measurements (adapted from Van Boxtel et al., 2011).

correlations between the alpha power recorded with the two systems were: 0.88 (C3, eyes open), 0.80 (C3, eyes closed), 0.88 (C4, eyes open) and 0.84 (C4, eyes closed) In sum, our novel system using water-based electrodes trained alpha activity at central sites very well.

3.2 Alpha Power in QEEG Measurements

We tested the relative alpha power (8-12 Hz / 4-35 Hz) for posterior electrodes on C3, C4, P3, P4, O1, and O1. As expected, alpha power was larger for eyes closed than for eyes open ($F(1,47) = 491.15$, $p < 0.001$, power = 1.00) conditions, and larger at occipital and parietal electrodes compared to central electrodes ($F(2,94) = 8.06$, $p < 0.001$, power = 0.95). In all three groups, alpha power increased over sessions ($F(2,90) = 66.96$, $p < 0.001$, power = 1.00). Importantly, the increase in relative alpha power was largest for the alpha training group ($F(4,90) = 20.60$, $p < 0.001$, power = 1.00), especially in the eyes open condition ($F(4,89) = 6.39$, $p < 0.001$, power = 0.99).

Figure 2 provides a visual representation of this effect. The figure not only shows the greatest alpha power increase in the alpha training group, but also that alpha levels, especially in the eyes open condition, continued to increase to follow-up measurement three months later. Apparently, the participants in the alpha group learned how to control their alpha level and were able to increase it further.

3.3 Relaxation

(For the outcome of the questionnaires, see Van Boxtel et al., 2011). As a qualitative relaxation measure, we examined how many participants in each group indicated that the training sessions were relaxing, without them being prompted. We did not inform the participants that this study was about relaxation, and asked them neutrally about how they experienced the training. In the alpha training group (A), 53% of the participants spontaneously remarked that they experienced the training sessions as relaxing, as opposed to 20% in the random beta group (B) and 21% in the music only control group (C).

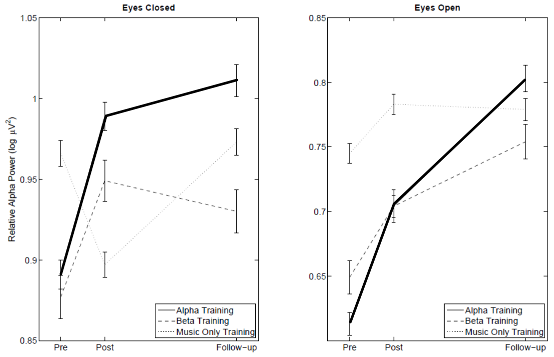

Figure 2: alpha power changes over sessions in the three groups (left: eyes closed, right: eyes open condition; adapted from Van Boxtel et al., 2011).

4 DISCUSSION

The purpose of this study was to investigate whether alpha activity training using an innovative self-guided system with water-based electrodes mounted in an audio headset was feasible.

There are several indications that supported the feasibility of our relaxation tool. First, the system with water-based electrodes was able to record EEG in the alpha range, of which the spectral properties correspond to what is usually reported in the literature. Alpha power recorded with the conventional QEEG system and with our novel system was statistically indistinguishable. This fact supports the use of our neurofeedback tool, which is very easy and less time consuming to use: no pastes or gels are required for training.

Second, alpha training using our novel system resulted in an increase in alpha activity as recorded using the conventional QEEG system. Even though the alpha group significantly increased most in alpha power, a weak point could be the fact that alpha activity already differed between groups during pre-measurement. Possibly, the music only group did not increase in alpha power, because their alpha activity already was higher at the beginning of the experiment.

It was also found that training of alpha activity at central sites increased alpha activity more posteriorly. This is a quite surprising finding, although to some extent consistent with others who have found that neurofeedback training can lead to changes beyond target frequency and location (e.g., Egner et al., 2004). In all statistical tests, alpha activity levels were largest at the occipital electrodes, with parietal electrodes also displaying considerable activity. This is what is usually reported for the classical alpha rhythm (Shaw, 2003). It is unclear how the activity in central and posterior areas is related.

Another important result of the present study is that the increase in alpha activity persisted, and increased slightly, at the follow-up session three months after the last training session. It is possible that the participants in the alpha training group learned to produce a solid alpha rhythm that they could possibly evoke at will whenever needed. Such a possibility not only supports the conclusion that use of such an innovative self-guided system can elicit learning, but that due to the self-guided nature of the learning it is also more easily maintained. However, further research is needed in order to substantiate such a claim.

Alpha activity that can be measured over the central scalp is called the mu or sensorimotor rhythm (SMR). Even though this rhythm can block in response to motor action (Pfurtscheller & Aranibar, 1979), we wanted to know whether training at central sites is related to subjectively experienced relaxation and whether central training generalises to alpha activity in other brain areas. Namely, there is some evidence that training of brain rhythms may generalise over the scalp (e.g., Egner, Zech, & Gruzelier, 2004).

The inclusion of two control conditions is a strong point of the present study, which demonstrates trainability of alpha activity beyond doubt. Alpha activity recorded with the eyes open exhibited the largest increase. It is tempting to relate these findings to the fact that the alpha training was given with the eyes open. However, the differential effects of training with eyes open and eyes closed on post-training recordings of eyes open and eyes closed activity, is not well studied (see Vernon et al., 2009).

Using a random beta training protocol as a control, as utilised by Hoedlmoser and colleagues (2008), and also recently applied in the gamma neurofeedback studies of Keizer and co-workers (2010), seemed to work quite well. Importantly, the random beta group did not get any adverse effects of the random beta training. Hence, random beta might be considered an appropriate control. For the alpha training group, a training approach based on the individual alpha peak frequency (IAF; Klimesch, 1996) would allow, in the future, for a more individualised and probably more effective training scheme.

We did see that alpha activity training produced more alpha activity along with subjective relaxation than the control groups did. This is surprising because listening to music by itself could be considered to be a relaxing experience. Our research would suggest that combining alpha activity training with listening to music adds an extra degree of relaxation.

However, using the participant's own favourite music for auditory feedback might have disturbed our relaxation goal, because of the fact that music might arouse one (Van der Zwaag et al., 2011). We tried to filter this influence out as much as possible by using the participant's own favourite music they liked to hear during training sessions. Again, any sort of music was allowed. Maybe it would be nice to combine studies (Van der Zwaag et al., 2011) to create even more efficient alpha training and optimize relaxation effects.

To sum up, we compared training of alpha activity to training of random beta and music only control, and found that alpha activity training at central sites enhanced alpha activity at posterior sites. We have demonstrated the feasibility of alpha activity training using an easy, wireless, water-based electrode system combined with an intuitive form of auditory feedback based on the participant's own favourite music. We consider our system to be an important step forward in the development of a system for instrumental conditioning of brain rhythms that can be used both in the clinic as well as at home. In our view, the availability of such a system would solve a number of technical weaknesses that surround such systems currently, so that more emphasis can be placed on factors that really matter in these studies, such as the protocols to be used, the number and nature of the training sessions, the influence of different instrumental conditioning schedules, and the transfer of the trained brain area to other areas, to name but a few.

REFERENCES

Angelakis, E., Stathopoulou, S., Frymiare, J. L., Green, D.

L., Lubar, J. F., & Kounios, J. (2007). EEG neurofeedback: a brief overview and an example of peak alpha frequency training for cognitive enhancement in the elderly. The Clinical Neuropsychologist, 21(1), 110-129.

Berger, H. (1929). Über das Elektrenkephalogram des Menschen. Archiv für Psychiatrie, 87, 527-570.

Bazanova, O., & Aftanas, L. (2008). Individual EEG alpha-indices and nonverbal creativity in female during the spontaneous menstrual cycle in comparison with male subjects. Annals of General Psychiatry, 7, S101.

Cabral, R.J., & Scott, D.F. (1976). Effects of two desensitization techniques, biofeedback and relaxation, on intractable epilepsy: follow-up study. Journal of Neurology, Neurosurgery, and Psychiatry, 39, 504-507.

Chorbajian, T. (1971). Nomographic approach for the estimation of heart rate recovery time from exercise in humans. Journal of Applied Physiology, 31, 962-964.

Dempster, T., & Vernon, D. (2009). Identifying indices of learning for alpha neurofeedback training. Applied Psychophysiology and Neurofeedback, 34, 309-318.

Egner, T., Strawson, E., & Gruzelier, J.H. (2002). EEG signature and phenomenology and alpha/theta neurofeedback following training versus mock feedback. Applied Psychophysiology and Biofeedback, 27, 261-270.

Egner, T., Zech, T.F., & Gruzelier, J.H. (2004). The effects of neurofeedback training on the spectral topography of the electroencephalogram. Clinical Neurophysiology, 115, 2452-2460.

Goldman, R.I., Stern, J.M., Engel Jr., J., & Cohen, M.S. (2002). Simultaneous EEG and fMRI of the alpha rhythm. Neuroreport, 13, 2487-2492.

Gruzelier, J.H. (2002). A review of the impact of hypnosis, relaxation, guided imagery and individual differences on aspects of immunity and health. Stress, 5, 147-163.

Hardt, J. V., & Kamiya, J. (1978). Anxiety change through electroencephalographic alpha feedback seen only in high anxiety subjects. Science, 201(4350), 79-81.

Herbert, R., & Tan, G. (2004). Quantitative EEG phase evaluation of Transcendental Meditation. Journal of Neurotherapy, 8(2), 120-121.

Keizer, A.W., Verschoor, M., Verment, R.S., & Hommel, B. (2010). The effect of gamma enhancing neurofeedback on the control of feature bindings and intelligence measures. International Journal of Psychophysiology, 75, 25-32.

Klimesch, W. (1997). EEG alpha rhythms and memory processes. International Journal of Psychophysiology, 26, 319-340.

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Research Reviews, 29, 169-195.

Klimesch, W., Sauseng, P., & Hanslmayr, S. (2007). EEG alpha oscillations: The inhibitiontiming hypothesis. Brain Research Reviews, 53, 63-88.

Lindsley, D.B. (1960). Attention, Consciousness, Sleep and Wakefulnes. Handbook of Physiology: Neurophysiology. American Physiological Society.

McNair, D. M., Lorr, M., & Droppleman, L. F. (1971). Manual for the Profile of Mood States. San Diego, CA: Educational and Industrial Testing Services. Mental Health Policies and Programmes in the Workplace (2005). Geneva, World Health Organization (Mental Health Policy and Service Guidance Package).

Nowlis, D.P., & Kamiya, J. (1970). The control of electroencephalographic alpha rhythms through auditory feedback and the associated mental activity. Psychophysiology, 6, 476-484.

Nunez, P.L. (1995). Neocortical Dynamics and Human EEG rhythms. London: Oxford University Press.

Perlini, A.H., & Spanos, N.P. (1991). EEG alpha methodologies and hypnotisability: A critical review. Psychophysiology, 28, 511-530.

Pfurtscheller, G., & Aranibar, A. (1979). Evaluation of event-related desynchronization (ERD) preceding and following voluntary self-paced movement. Electroencephalography and Clinical Neurophysiology, 46, 138-146.

Rice, K. M., Blanchard, E. B., & Purcell, M. (1993). Biofeedback treatments of generalised anxiety disorder: Preliminary results. Biofeedback and Self Regulation, 18, 93-105.

Shaw, J.C. (2003). The Brain's Alpha Rhythms and the Mind. Amsterdam: Elsevier.

Vander Sloten, P. Verdonck, M. Nyssen & J. Haueisen (Eds.). IFMBE Proceedings, 22, 1022-1025.

Thatcher, R.W., Krause, P.J., & Hrybyk, M. (1976). Cortico-cortical associations and EEG coherence: a two-compartment model. Electroencephalograhy and Clincical Neurophysiology, 64, 123-143.

Verleger, Gasser, T., & Möcks, J. (1982). Correction of EOG artifacts in event-related potentials of the EEG: Aspects of reliability and validity. Psychophysiology, 19, 472- 480.

Van Boxtel, G.J.M., Denissen, A., Jager, M., Vernon, D., Dekker, M.K.J., Mihaljovic, V. & Sitskoorn, M.M. (2011). A novel approach to alpha activity training. International journal of psychophysiology, In Press.

Vernon, D. (2005). Can neurofeedback training enhance performance? An evaluation of the evidence with implications for future research. Applied Psychophysiology and Biofeedback, 30, 347-364.

Vernon, D., Dempster, T., Bazanova, O., Rutterford, N., Pasqualini, M., & Andersen, S. (2009). Alpha neurofeedback training for performance enhancement: Reviewing the methodology. Journal of Neurotherapy, 13, 1-13.

Watson, C. G., Herder, J., & Passini, F. T. (1978). Alpha biofeedback theory in alcoholics: An 18-month follow-up. Journal of Clinical Psychology, 34(2), 765-769.

Welch, P.D. (1967). The use of fast Fourier transforms for the estimation of power spectra: A method based on time averaging over short modified periodograms. IEEE Transactions on Audio and Electroacoustics, 15, 70-73.