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DOUBLE-BLIND AND SHAM-CONTROLLED AUGMENTED REALITY EEG-NEUROFEEDBACK STUDY

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ABSTRACT: Traditional Neurofeedback (NF) designs are rather dull and only little engaging, which can negatively influence training performance. NF profits from interesting paradigms implementable through tools such as Virtual and Augmented Reality (AR). AR, however, is still very new in the field of NF and BCI but seems promising in hindsight of less Cybersickness and easier and cheaper usage for tele-rehabilitation, as modern smartphones support AR implementations. However, there are still no sham-controlled AR-based NF studies with larger samples. We propose a one-session sham-controlled and double-blinded NF study comparing AR with 2D feedback. The NF training consisted of sensorimotor rhythm (SMR) up-regulation and we tested 89 healthy participants. Results showed a numerically but non-significant increase in SMR across the NF runs in all four groups. Sham and real feedback groups did not differ in their performance. The study could show that AR is equally viable to 2D feedback and participants were not able to increase SMR within one NF training session.

Keywords: Augmented Reality, Neurofeedback, Sensorimotor Rhythm

INTRODUCTION

Since about 30% of Brain-Computer Interface (BCI) users are not able to alter their own brain activation [1], neurofeedback (NF) and BCI alike profit a lot from engaging and interesting paradigms in order to increase training adherence of the users. Psychological factors such as motivation [2] and attention [3] from the users are positively associated with the NF training success. Virtual Reality (VR) has in respect thereof already shown to be beneficial to increase NF performance [4] over simple traditional 2D paradigms presented on computer screens. Further, stroke patients undergoing VR NF training also reported a high motivation to continue their training and showed high interest [5]. However, VR presents some downsides in its usage as well. About 80% of the users of VR systems are prone to develop symptoms of Cybersickness, such as nausea, oculomotor problems or disorientation [6], which can on the one hand lead to a worse user experience and on the other hand to a worse training outcome [7]. Also, VR is costly on resources to offer for a group of patients on a tele-rehabilitation basis, and there are only little options of combined VR-EEG systems. Another option that is posing some advantages over VR but is still only little researched in the field of NF and BCI is the application of Augmented Reality (AR). Here, virtual objects are superimposed on real world surroundings. On the reality-virtuality continuum proposed by Milgram and Kishino, AR is classified as closer to reality than VR [8]. The implementation is done by using, e.g., smartphones, webcams, or stereoscopical camera additions to VR goggles. An advantage of AR is that it is less prone to result in the feelings of Cybersickness [9] in the user. They experience less nausea and disorientation during the usage. Further, AR seems more easily applicable for tele-rehabilitation purposes, as most modern smartphone cameras support AR (official list: https://developers.google.com/ar/devices). So here no expensive combinational devices would be necessary. AR enables new opportunities to integrate feedback and bodily features can still be visible and can if necessary be included to the feedback. It hence offers the creation of adaptive paradigms that support the training. [10]

However, there is a lack of double-blind sham-controlled AR-NF studies and only a handful of studies are using AR in NF settings. In one study from 2014 the researchers created the MindMirror, using a Webcam with a virtual overlay to simulate an AR setting [11]. Participants would see themselves on a computer screen over a webcam with a virtual brain overlay presented on their heads. For the training relevant areas would light up in different colors. Viczko et al. used an AR NF paradigm for a NF meditation application using an Apple iPhone and Emotive headband for the feedback. It showed butterflies hatching from crystals when brain activity reached the desired state and could then be followed with the phone camera as an interactive element [12]. Also, there are several proof-of-concept studies with relatively small samples (5-12 participants in total [13, 14] and no sham-control groups, combining for example steady-state visual evoked potential (SSVEP) based BCI systems [15]. The presented studies offered a first insight into combinational AR-BCI and NF studies.

Altogether, studies with big sample sizes and double-blinded sham-control are still missing. Here, we conducted an EEG-based NF study comparing AR feedback with conventional 2D bar feedback design with regard to NF performance (measured as SMR increase over the course of six feedback runs). We hypothesized that participants from the AR group would perform better in a SMR-NF task than participants undergoing a 2D NF with a conventional paradigm. Since VR paradigms have previously been shown to result in better NF performance

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compared to 2D paradigms [4, 16] and AR has previously been successfully tested in the field of BCI and rated very positively by participants [11], we expected similar positive NF results for AR-feedback compared to 2D feedback. Also, we assumed participants receiving real feedback would perform better than the feedback group receiving sham feedback. Previous findings in the general field of NF could show beneficial training effects specifically for real feedback groups compared to sham feedback groups [17, 18]. Hence, we expected similar results in our sample with AR-based NF.

MATERIALS AND METHODS

The study was conducted at the University of Graz. All participants gave written informed consent before the start of the measurement. The ethics committee of the University of Graz, Austria, approved all aspects of the present study in accordance with the Declaration of Helsinki (GZ. 39/119/63 ex 2021/22).

Participants: In total, 100 participants were tested (see Table 1). Eleven datasets had to be excluded from the statistical analysis due to bad EEG data quality, problems with the paradigm and drop-outs, hence, 89 datasets survived for further analysis. Forty-four participants performed the 2D NF task, 45 the AR task (see Table 1). All volunteers had normal or corrected-to-normal vision, no neurological, psychological or other severe diseases, as well as no reflex epilepsy. They gave written informed consent and were either paid for their participation (16€) or received research credit hours for their Psychology Bachelor program.

Table 1: Description of the sample.

	AR		2D	
	real	sham	real	sham
N (female)	25 (14)	20 (12)	20 (9)	24 (17)
Mean age (SD)	23.76 (3.31)	24.95 (3.82)	24.65 (4.06)	21.79 (1.74)
Responder	16	12	10	14
Non-Resp.	9 (36%)	8 (40%)	10 (50%)	10 (41.6%)

Neurofeedback-training: Participants were pseudo-randomized and assigned to one of the four groups: 2D vs. AR feedback, real vs. sham feedback and experimenters just as participants were blinded whether real or sham feedback was given. In the real feedback condition participants got their real brain activation fed back in real time, while in the sham feedback condition the brain activation from another person of another (similar) study was fed back [4]. In the AR condition, participants would see three virtual plants growing out of real plant-pots placed in front of them. The middle one represented the sensorimotor rhythm (SMR; 12-15 Hz) recorded over Cz and the two outer plants Theta (4-7 Hz) and Beta (16-30 Hz), also recorded over electrode position Cz. Participants should make the middle one grow as high as possible and keep the two outer ones as low as possible. The same principle was followed by the 2D paradigm, only they saw three 2D bars equally representing the three frequency bands regularly on a PC screen (see Figure 1). The training consisted of a baseline run and six training runs of three minutes each. In the baseline run, participants were instructed to watch the moving objects without trying to influence it. Afterwards, individual threshold values were calculated based on this baseline activation. For SMR the mean values were calculated and for Theta and Beta the mean plus one standard deviation was calculated. The thresholds were adapted in the paradigm for the training after each run and participants were instructed to be physically relaxed and mentally focused to control the feedback objects.

Technology: The AR paradigm was presented via the HTC Vive Pro VR-System. The stereoscopical camera ZED mini from Stereolabs was attached to the VR goggles to enable AR vision. The SDK Unity Plugin version 3.8.0 was used to create the environments in Unity, Version 2020.3.30f1 (see Figure 2). For superimposing the virtual objects in the AR setting via markers, the free Unity trial version of OpenCV (version 2.4.8) was used. For real-time EEG data streaming the LSL4Unity plugin, freely available at https://github.com/labstreaminglayer/LSL4Unity was used in combination with OpenViBE, Version 3.3.0. OpenViBE is a free software to stream and preprocess EEG data in real-time. The framerate of both the camera and computer screen were set to 60 FPS. Even though the 2D group got their paradigm presented on a computer screen, they also had to wear the VR-AR system to rule out any group differences related to wearing the system, such as headache or pressure sensations due to wearing the whole system. Here, the camera was simply switched on, so participants would also see their surroundings through the camera.

EEG recording and Offline EEG data processing: Data was recorded with the gUSBamp RESEARCH EEG-amplifier from g.tec medical engineering and a sampling rate of 500Hz. We used 16 sintered Ag/AgCl passive ring electrodes, placed according the 10-20 EEG-system, to measure the signal. All electrodes were referenced against left mastoid and the ground was placed at FPz. A right mastoid placed electrode was used to calculate linked mastoid reference during the offline EEG data processing. Brain Vision Analyzer (version 2.2, Brain Products GmbH, Munich, Germany) was used for offline EEG-data processing. At first, a 50 Hz notch filter and a low cutoff filter of 0.01, as well as a high cutoff filter of 100 Hz were applied. Further, big muscle artifacts were excluded and heavy drifts during the raw data inspection. Data was referenced to the linked mastoid reference to rule out hemisphere effects, as the left mastoid was the primary reference electrode. Next, a semi-automatic independent component analysis (ICA) was performed to eliminate blinks and eye movements using a semi-automatic independent component analysis (ICA). Lastly, a second semi-automatic data inspection followed to exclude additional remaining artifacts that survived the other

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preprocessing steps (Criteria for rejection: maximum allowed voltage step of 50µV/ms, maximum allowed difference between values in a segment was 200 µV, amplitudes ± 120 µV, lowest allowed activity in 100 ms intervals was 0.5 µV, artifacts were marked 200 ms before and after emergence). Finally, the frequency power bands in the ranges 12-15 Hz (SMR), 4-7 Hz (Theta) and 16-30 Hz (Beta) were extracted using complex demodulation. Data was segmented into 1s intervals and segments with artifacts were removed.

Figure 1: The used AR-Set-up with the HTC Vive Pro and attached ZEDmini stereoscopical camera. On the table one can see the plant pots and the screen shows the virtual plants that the participant is seeing via the VR-googles.

Questionnaires: In this study we also assessed the user experience of participants with several questionnaires on Cybersickness, technology anxiety, subjective control among others. Results are presented in another study which is currently under submission.

Statistical Analysis: To investigate the NF performance (measured as the changes in SMR power across six NF runs) of the four different groups (AR real vs. AR sham and 2D real vs. 2D sham), a linear mixed effect model with three fixed factors (group, condition, feedback runs) was calculated for the dependent variable SMR power over electrode position Cz (Type I Sum-of Squares Analysis of Variance with Satterthwaite's method). Here, we will only present the findings for SMR. To enable a better interpretation of the results we split the factor runs in two groups, one for the first training half (first three runs) and one for the second training half (runs four to six). The factor subject was included in the model as crossed random effect.

To identify non-responders, we checked whether regression slopes were increasing or decreasing. They were determined by calculating a regression with SMR power as criterion and feedback run number as predictor. Positive slopes indicate a linear increase, showing a successful training and negative slopes a linear decrease, showing an unsuccessful training. To investigate whether non-responders are equally distributed between all four groups we calculated a Chi-Squares test.

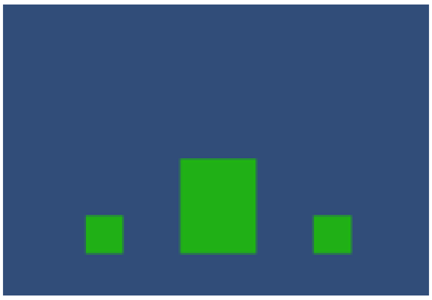

Figure 2: Traditional 2D paradigm presented on PC screen.

RESULTS

The results of the linear mixed effect model showed no group-differences of AR/2D or real/sham feedback groups (for F-statistics see Table 2). Although SMR power increased numerically over the training runs, the main effect Runs was not significant (Table 2, Figure 3).

Table 2: F-statistics of the Linear Mixed Effect Model with Group (AR/2D), Condition (real/sham), and Runs as fixed factors.

Object	*F*	*df*	*p*
Group	0.32	1,234.31	.572
Runs	0.01	1,437.25	.925
Condition	0.01	1,234.73	.928
Group*runs	0.03	1,437.21	.855
Group*condition	0.07	1,233.65	.788
Runs*condition	0.16	1,437.21	.691
Group*runs*condition	0.12	1,437.16	.730

Figure 3: Line graph showing the training performance of all the four groups over the course of the six feedback runs. Error bars are indicating the standard error.

Responder/Non-responder: In our sample 41.6% of the users were not able to increase their brain activation across the six feedback runs (see Table 1). All groups had a similar number of non-responders (χ^2=0.93, *p* = .819).

DISCUSSION

We conducted a study, comparing AR and 2D based

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SMR-NF training in a double-blinded pseudo-randomized and sham-controlled study with a large sample size (N=89). Statistical analyses revealed no group differences in the NF performance, all four groups showed a comparable small but non-significant increase in the target frequency band over the course of six feedback runs.

In the present study, we did not find any differences in NF performance between the AR and 2D condition within one NF training session. Hence, AR-based NF training had no beneficial effects over conventional feedback designs. Previous studies also found comparable results of conventional and AR NF-paradigms. In a one-session user study from Mercier-Ganady and colleagues (2014) using a webcam to overlay a virtual brain on the users' heads also showed comparable results between the AR and a conventional 2D training, where they used a representation of a temporal gauge. Participants reported that their AR paradigm was less clear but more innovative and original. The EEG results were equal for both groups [11]. Hence, it seems as if only one NF training session was not enough to reveal possible beneficial effects of AR-based NF training. It would be interesting to compare training results over a longer period with trainings consisting of multiple sessions instead of only one to see, whether AR-based feedback might be beneficial for NF training performance over a longer training period.

Further, both of our paradigms were rather similar, each showing three objects growing and shrinking in size. This might explain the similar results for both conditions. Other studies in this field had either no control group [19] or control groups where the outcome or visual feedback differ fundamentally between the two groups. For instance, previous studies investigated the effects of AR-based meditation with and without NF on mood [12], or compared a visual feedback where participants should light up an AR brain-overlay with. a temporal gauge as feedback [11]. Future studies should try explore more AR-given possibilities of design and interaction. In a further study one could for example expand the flower idea we used in the current study but for example make the task to turn the whole laboratory into a flowerbed surrounding the participants.

Mohammed et al. speculate that AR-BCI studies would result in a higher cognitive load as it being more cognitively demanding [10]. However, AR still serves less visual distraction than does VR with its surrounding virtual environments. In a review on the impact of AR on tasks performances and cognitive load it could be shown that when using AR to complete different tasks, participants have less or equal cognitive load, as well as a higher performance than those using conventional methods [20]. It remains open, whether these results also reflect AR usage in NF. To overcome the problem of complexity for the participants it might be beneficial to implement introductory sessions where participants could familiarize with the systems.

Further, we found no group differences between real and sham feedback groups. Even though one would expect better NF performance in real feedback groups compared to sham groups, it is not uncommon to find comparable results in the NF literature especially when performing only one NF training session [21]. Ninaus et al. (2013) could show in an fMRI based NF study that both participants from the real and the sham feedback group showed similar active neural networks [22]. Participants and experimenters were blinded concerning group allocation and were instructed the same way. Hence, both groups were instructed to be mentally focused and physically relaxed. In a review on ADHD and neurofeedback researchers propose that effects from neurofeedback need more time in terms of more training sessions to develop. It is possible that during familiarizing with the task in the first 20-30 minutes, attention and concentration increased naturally, leading to unspecific changes in EEG activity, which are not related to real NF conditions [23].

Finally, the number of non-responders in this study is a bit higher than in other studies, where mostly 30% are reported [1, 24]. However, non-responders of up to 50% can be observed in the literature [25]. The AR group did not have less non-responders than the 2D group and the number also did not differ between sham and real feedback groups. It is difficult to determine non-responders within a single training session, as it is still an intensive learning process and for most participants it was their first NF training. Here unspecific factors might also play a big role, especially with a rather complex set-up used in our study. It would also be interesting to see whether the number of non-responders within the groups would change after several training sessions.

CONCLUSION

In the current study we did not find any differences in NF performance between an AR NF training and a conventional 2D feedback within one NF training session. Expanding the AR paradigm to a more complex task should shed more light on paradigm differences on the NF performance in future studies. Also, sham and real feedback led to a comparable NF performance.

References

[1] Allison BZ, Neuper C. Could Anyone Use a BCI? In: Tan DS, Nijholt A, editors. Brain-Computer Interfaces. London: Springer London 2010; 35–54.

[2] Kleih SC, Nijboer F, Halder S, Kübler A. Motivation modulates the P300 amplitude during brain-computer interface use. Clin Neurophysiol 2010; 121(7): 1023–31 [https://doi.org/10.1016/j.clinph.2010.01.034][PMID: 20188627]

[3] Hammer EM, Halder S, Blankertz B, *et al.* Psychological predictors of SMR-BCI performance. Biol Psychol 2012; 89(1): 80–6 [https://doi.org/10.1016/j.biopsycho.2011.09.006][PMID: 21964375]

[4] Berger LM, Wood G, Kober SE. Effects of virtual reality-based feedback on neurofeedback training

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10.3217/978-3-99161-014-4-071

performance-A sham-controlled study. Front Hum Neurosci 2022; 16: 952261 [https://doi.org/10.3389/fnhum.2022.952261][PMID: 36034118]
[5] Kober SE, Reichert JL, Schweiger D, Neuper C, Wood G. Effects of a 3D Virtual Reality Neurofeedback Scenario on User Experience and Performance in Stroke Patients. In: Bottino R, Jeuring J, Veltkamp RC, editors. Games and Learning Alliance. Cham: Springer International Publishing 2016; 83–94.
[6] Rebenitsch L, Owen C. Review on cybersickness in applications and visual displays. Virtual Reality 2016; 20(2): 101–25 [https://doi.org/10.1007/s10055-016-0285-9]
[7] Berger LM, Wood G, Kober SE. Influence of a placebo tDCS treatment on Cybersickness and EEG-Neurofeedback success. Behav Brain Res 2024: 114917 [https://doi.org/10.1016/j.bbr.2024.114917][PMID: 38401602]
[8] Skarbez R, Smith M, Whitton MC. Revisiting Milgram and Kishino's Reality-Virtuality Continuum. Front. Virtual Real. 2021; 2 [https://doi.org/10.3389/frvir.2021.647997]
[9] Hughes CL, Fidopiastis C, Stanney KM, Bailey PS, Ruiz E. The Psychometrics of Cybersickness in Augmented Reality. Front. Virtual Real. 2020; 1 [https://doi.org/10.3389/frvir.2020.602954]
[10] Si-Mohammed H, Argelaguet F, Casiez G, Roussel N, L, cuyer A. Brain-Computer Interfaces And Augmented Reality: A State Of The Art. Verlag der Technischen Universität Graz; 2017.
[11] Mercier-Ganady J, Lotte F, Loup-Escande E, Marchal M, Lecuyer A. The Mind-Mirror: See your brain in action in your head using EEG and augmented reality. In: The Mind-Mirror: See your brain in action in your head using EEG and augmented reality; 2014. IEEE; 33–8.
[12] Viczko J, Tarrant J, Jackson R. Effects on Mood and EEG States After Meditation in Augmented Reality With and Without Adjunctive Neurofeedback. Front. Virtual Real. 2021; 2 [https://doi.org/10.3389/frvir.2021.618381]
[13] Benitez-Andonegui A, Burden R, Benning R, Möckel R, Lührs M, Sorger B. An Augmented-Reality fNIRS-Based Brain-Computer Interface: A Proof-of-Concept Study. Front Neurosci 2020; 14: 346 [https://doi.org/10.3389/fnins.2020.00346][PMID: 32410938]
[14] Huang X, Mak J, Wears A, *et al.* Using Neurofeedback from Steady-State Visual Evoked Potentials to Target Affect-Biased Attention in Augmented Reality. Annu Int Conf IEEE Eng Med Biol Soc 2022; 2022: 2314–8 [https://doi.org/10.1109/EMBC48229.2022.9871982][PMID: 36085716]
[15] Faller J, Allison BZ, Brunner C, *et al.* A feasibility study on SSVEP-based interaction with motivating and immersive virtual and augmented reality. arXiv; 2017.
[16] Berger AM, Davelaar EJ. Frontal Alpha Oscillations and Attentional Control: A Virtual Reality Neurofeedback Study. Neuroscience 2018; 378: 189–97 [https://doi.org/10.1016/j.neuroscience.2017.06.007][PMID: 28642166]
[17] Ramos-Murguialday A, Broetz D, Rea M, *et al.* Brain-machine interface in chronic stroke rehabilitation: a controlled study. Ann Neurol 2013; 74(1): 100–8 [https://doi.org/10.1002/ana.23879][PMID: 23494615]
[18] Schabus M, Heib DPJ, Lechinger J, *et al.* Enhancing sleep quality and memory in insomnia using instrumental sensorimotor rhythm conditioning. Biol Psychol 2014; 95: 126–34 [https://doi.org/10.1016/j.biopsycho.2013.02.020][PMID: 23548378]
[19] Rajshekar Reddy GS, G.M. L. A Brain-Computer Interface and Augmented Reality Neurofeedback to Treat ADHD: A Virtual Telekinesis Approach. In: A Brain-Computer Interface and Augmented Reality Neurofeedback to Treat ADHD: A Virtual Telekinesis Approach; 2020. IEEE; 123–8.
[20] Buchner J, Buntins K, Kerres M. The impact of augmented reality on cognitive load and performance: A systematic review. Computer Assisted Learning 2022; 38(1): 285–303 [https://doi.org/10.1111/jcal.12617]
[21] Schabus M, Griessenberger H, Gnjezda M-T, Heib DPJ, Wislowska M, Hoedlmoser K. Better than sham? A double-blind placebo-controlled neurofeedback study in primary insomnia. Brain 2017; 140(4): 1041–52 [https://doi.org/10.1093/brain/awx011][PMID: 28335000]
[22] Ninaus M, Kober SE, Witte M, *et al.* Neural substrates of cognitive control under the belief of getting neurofeedback training. Front Hum Neurosci 2013; 7: 914 [https://doi.org/10.3389/fnhum.2013.00914][PMID: 24421765]
[23] Vollebregt MA, van Dongen-Boomsma M, Buitelaar JK, Slaats-Willemse D. Does EEG-neurofeedback improve neurocognitive functioning in children with attention-deficit/hyperactivity disorder? A systematic review and a double-blind placebo-controlled study. J Child Psychol Psychiatry 2014; 55(5): 460–72 [https://doi.org/10.1111/jcpp.12143][PMID: 24168522]
[24] Thompson MC. Critiquing the Concept of BCI Illiteracy. Sci Eng Ethics 2019; 25(4): 1217–33 [https://doi.org/10.1007/s11948-018-0061-1][PMID: 30117107]
[25] Khodakarami Z, Firoozabadi M. Psychological, Neurophysiological, and Mental Factors Associated With Gamma-Enhancing

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10.3217/978-3-99161-014-4-071

Neurofeedback Success. Basic Clin Neurosci 2020; 11(5): 701–14 [https://doi.org/10.32598/bcn.11.5.1878.1][PMID: 33643562]

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