Sex Differences in User Experience in a VR EEG Neurofeedback Paradigm

Lisa M. Berger[1(✉)], Guilherme Wood[1,2], Christa Neuper[1,2], and Silvia E. Kober[1,2]

[1] Institute of Psychology, University of Graz, Universitaetsplatz 2/III, 8010 Graz, Austria
{lisa.berger,guilherme.wood,christa.neuper, silvia.kober}@uni-graz.at
[2] BioTechMed-Graz, Mozartgasse 12/II, 8010 Graz, Austria

Abstract. In brain-computer interface applications such as neurofeedback (NF), traditional 2D visual feedback has been replaced frequently by more sophisticated 3D virtual reality (VR) scenarios. VR is considered to be more motivating and to increase NF training success. However, hard evidence on user experience in set-ups combining VR-EEG NF has been scarcely reported. Hence, we evaluated user experience on cybersickness, discomfort/pain, technology acceptance and motivational factors and compared them between a 3D and a 2D VR scenario. Additionally, we focused on possible sex differences. 68 subjects received one VR-neurofeedback session with either a 3D or 2D VR paradigm. Statistical analyses showed that sickness was higher after the VR-NF training than before, and women experienced higher sickness values than men. Further, women reported more subjective pressure sensations on the head, eye burning and headache, as well as higher technology anxiety, less perceived usefulness of the used technology and less perceived technology accessibility. No dimensionality or sex differences regarding subjective feeling of flow and presence were found. Moreover, no differences between the 3D and 2D VR scenarios were observed. Our results indicate sex differences in user experience in VR-based NF paradigms, which should be considered when using VR as feedback modality in future NF applications. In contrast, 3D or 2D presentation of the VR scenario did not affect user experience, indicating that more immersive 3D VR scenarios do not cause more negative side effects than the less immersive 2D VR scenario.

Keywords: Virtual reality · Neurofeedback · EEG

1 Introduction

Neurofeedback is a brain-computer interface (BCI) where the aim is to learn how to alter voluntarily one's own brain activity. Here, brain activation patterns are acquired mostly by measuring cortical electric current fluctuations with Electroencephalography (EEG). Activation is then preprocessed in real-time and fed back to the user [15]. Modulating brain activation patterns in a desired direction using NF is used to improve cognitive

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or motoric performances in the context of neurorehabilitation and neuropsychological training [17], sports [33], acting performance [6], or improving sleeping quality [23].

Neurofeedback often requires multiple training sessions, sometimes even up to 70–100 sessions [17, 29]. Having to complete the same task all over again can be tiresome and demotivating in the long run. Paradigms mostly consist of visual feedback, showing bars or circles that should be increased in size during the training session [12]. As neurofeedback is strongly dependent on psychological factors such as motivation [9], subjective feeling of presence [7] and locus of control [32], it seems desirable to investigate factors increasing those subjective states, to make the training less tiresome and more engaging. Virtual Reality thereby poses as a modern tool to give more immersive feedback and maybe increase training motivation [11], as well as training success [12].

Besides possible positive effects of VR-based feedback, negative effects on NF training should be investigated. For example, cybersickness can occur in 25–80% of the participants related to the usage of virtual environments [2, 26]. Symptoms of discomfort in virtual environments are quite common and disappear after about 2–6 min after usage [1]. They can, however, attenuate for example the feeling of presence [30], which can in turn influence training success of neurofeedback [7]. Hence, we designed two different VR paradigms, a 3D environment with a moving viewer perspective and the other with a static 2D environment, to investigate cybersickness.

Additionally, in a VR-EEG set-up, the head-mounted VR-system (VR goggles) is placed over the electrodes. What has never been reported in previous studies using a similar set-up is that this combinational set-up could cause headache or pressure sensations, since VR-goggles press against the electrodes on the head, as before mostly CAVE™-like surround projection screens have been used for VR induction. Therefore, we wanted to investigate pain and discomfort with visual analogue scales (VAS).

Further, sex differences in the user experience need to be considered, as men still perceive technology as more positive, than women [3]. Also, it has been reported that women experience less subjective feeling of control over technology usage and experience less self-efficacy [22]. Control beliefs can predict the upregulation of the sensorimotor rhythm [32], hence the neurofeedback success.

In this study, we therefore investigated different aspects of user experience and psychological constructs in 2D vs. 3D VR paradigm groups. Dimensionality and sex differences concerning technology perception, cybersickness and motivation were tested in healthy young adults in an EEG-based neurofeedback study.

2 Methods

2.1 Subjects

Seventy-six healthy participants were tested in this study and were randomly assigned to the 2D or 3D group. Inclusion criteria were the absence of neurological or psychiatric diseases and age of participants to be between 18–34 years old. Eight participants were excluded due to bad EEG data quality, technical problems and not fulfilling inclusion criteria. 68 subjects (Mean age = 23.21, $SD = 3.41$) were left for further analysis. As a reward, every participant could try out Google Earth in the Virtual Reality after the experiment and psychology students would get course credits for their participation.

All participants gave their written informed consent. The study was approved by the local ethics committee of the University of Graz, Austria and is in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans (WMA (World Medical Association), 2009).

2.2 Questionnaires

Technology Usage Inventory (TUI). This questionnaire [14] asks for the acceptance of technologies and psychological factors concerning the usage of technology. The items are divided into eight scales: curiosity, anxiety, interest, user friendliness, immersion, usefulness, scepsis and accessibility. Sum scores are calculated and transformed to stanines, ranging from 1 to 9, where higher values represent higher manifestations. Cronbach's Alpha shows an intern validity between .70 and .89.

Questionnaire for Current Motivation (FAM). The FAM [21] evaluates the momentary learning motivation in four scales: fear of failure, interest, success probability and challenge. Sum scores are calculated for interpretation, where higher values represent higher manifestations. Cronbach's Alpha range from .66 to .90.

Flow Short Scale (FKS). The Flow scale [20] evaluates the extent to which participants experienced flow with the three factors: Smooth automated procedure, absorbedness, and worry. A total sum score can be calculated as well as the sum scores of the three subscales. For the analysis, t-values were taken from the according norm-table. Internal consistency of Cronbach's Alpha lies at .90.

Igroup Presence Questionnaire. This questionnaire evaluates the grade in which people feel present in a VR [19]. The IPQ consists of three subscales: spatial presence, involvement and experienced realism and an additional item, not associated to any subscale. A sum score over all items can be calculated, as well as the scores for the three subscales. Higher values indicate higher manifestations. Cronbach's Alpha was tested in two studies, the first reported an Alpha between .80 and .85. The second study shows similar Alpha with .77–.87.

Simulator Sickness Questionnaire (SSQ). The SSQ [8] covers several physical symptoms such as nausea and headache The sum score is calculated, the higher the score, the higher the symptoms. Also, three subscales can be calculated: nausea (e.g. sweating, stomach awareness), oculomotor (e.g. blurred vision, eye strain), and disorientation (e.g. dizziness). This questionnaire was filled out before and after the neurofeedback training. The sum score and subscores each need to be multiplicated by weights, described elsewhere [8].

Visual Analogue Scale (VAS) on Physical Condition. This VAS was self-constructed to identify whether participants experienced headache or pain due to VR-googles and electrodes. Pain intensity levels could vary between values of 0 up to 100, the higher the values the greater the pain/discomfort.

Evaluation of Training Enjoyment. At the end of the neurofeedback session participants were asked in a single question, whether they had fun during the training. Frequencies were calculated.

2.3 Neurofeedback

After filling out questionnaires and having the EEG and VR montage done, participants had to undergo seven feedback-runs of 3 min each with short breaks in-between. The first run was a baseline run where they were told to just watch the target objects without trying to alter their brain activation in order to identify individual frequency-band thresholds for SMR (12–15 Hz), Theta (4–7 Hz) and Beta (16–30). SMR had to be kept high, whereas Theta and Beta should be held as low as possible, to avoid artifacts such as blinks or movements [28] as target objects would turn red and stop moving when they were too high.

The 2D paradigm showed one green two-dimensional vertically moving bar (see Fig. 1A) [12] in the virtual space. The bar would increase in its height, whenever the trained EEG-frequency was over the individually identified threshold and would decrease, whenever the frequency was below that threshold.

The 3D paradigm showed a forest environment (downloaded from TriForge Assets in the Unity Asset Store), where a green ball was rolling along a predefined path, collecting light blue floating objects. The ball would move, whenever the predefined threshold of the trained EEG-frequency was exceeded and it would stand still, whenever the frequency was below that threshold (see Fig. 1B). Half of the participants received the 2D paradigm and the other half received the 3D paradigm.

The HTC Vive Pro-System was used, and the VR environments were programmed in the game engine Unity 3D, Version 2018.3.1.4. The lab streaming layer LSL4Unity plugin, freely available at https://github.com/labstreaminglayer/LSL4Unity, was implemented to stream the incoming EEG data.

The gUSBamp RESEARCH EEG-amplifier from g.tec medical engineering was used for the EEG-acquisition. Feedback was given over the Cz electrode [11]. Real-time preprocessing was done via OpenViBE Version 2.2.0.

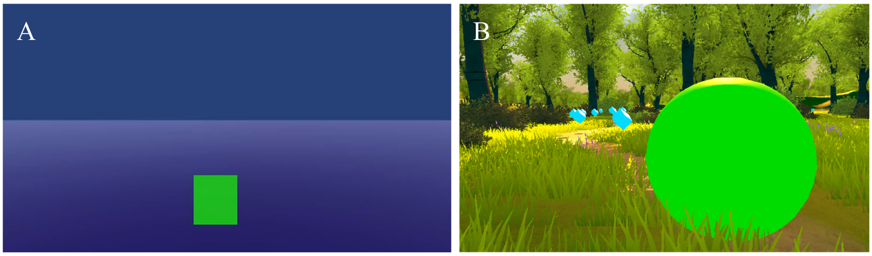

Fig. 1. A) 2D VR paradigm and B) 3D VR paradigm. Both were presented via the HTC-Vive Pro head-mounted VR goggles.

2.4 Statistical Analysis

To evaluate dimensionality and sex differences in cybersickness, an ANOVA with the between-subject factors dimensionality (2D vs. 3D) and sex, as well as one within-subjects factor time taking pre- and post-training into account, was conducted.

To analyze subjective values on physical condition and technology acceptance, ANOVAs with the between-subject factors dimensionality and sex were calculated for each VAS and subscales.

To investigate current motivation, we only took the between-subjects variable sex and calculated a Mann-Whitney-U Test. Finally, we checked for dimensionality and sex differences concerning enjoyment with a Chi-Square test.

2.5 Results

Simulator Sickness. SSQ sum score was higher after the training (M = 102.19, SE = 2.86) than before (M = 93.23, SE = 1.62). Women showed higher sickness (Pre: M = 97.68, SE = 2.57; Post: M = 110.77, SE = 4.79) than men (Pre: M = 88.77, SE = 1.67; Post: M = 93.61, SE = 2.43) at both time points. Oculomotor problems (M = 69.00, SE = 1.79) increased after the training (M = 80.59, SE = 3.07). Women showed higher values at both timepoints (Pre: M = 74.69, SE = 2.95; Post: M = 90.51, SE = 5.11) compared to men (Pre: M = 63.32, SE = 1.53; Post: M = 70.67, SE = 2.49) and disorientation (M = 105.22, SE = 1.47) was also significantly higher after the training (M = 119.55, SE = 3.10; see Table 1). Women showed higher levels at both timepoints (Pre: M = 107.68, SE = 2.37; Post: M = 129.37, SE = 4.79) than men (Pre: M = 102.76, SE = 1.66, Post: M = 107.76; SE = 3.21). Also, there was a significant interaction of sex and time (see Table 1) All other effects were non-significant.

Physical Condition. Women experienced more pressure sensations (M = 31.94, SE = 4.52) on the head than men (M = 18.35, SE = 2.76), more headache (M = 13.50, SE = 3.30) after the training than men (M = 3.47, SE = 1.47) and higher symptoms of eye burning (M = 14.97, SE = 3.74) than men (M = 5.71, SE = 1.50), with higher values of women in the 3D group (M = 22.18, SE = 6.56), compared to the 2D group (M = 7.76, SE = 2.86; see Table 1). Everything else was tested non-significant.

Technology Usage Inventory. Women reported less perceived usefulness of technology ($F(1, 64) = 4.55$, $p = .037$, $\eta_p 2 = .066$), higher technology anxiety ($F(1, 64) = 5.49$, $p = .022$, $\eta_p 2 = .079$) and less subjective accessibility of technology ($F(1, 64) = 4.89$, $p = .031$, $\eta_p 2 = .071$) than men. Finally, women reported significantly less interest ($F(1, 64) = 38.52$, $p = .000$; $\eta_p 2 = .376$; see Fig. 2). No other effects were shown.

Motivation/Enjoyment. The subscale fear of failure showed a tendency of higher fear in women (M = 12.03, SE = 1.03), compared to men (M = 9.15, SE = 0.76; $Z = -1.951$, $p = .051$). The effects of all the other subscales were non-significant.

Flow and Presence. No significant main effects of dimensionality (Presence: $F(1, 64) = .79$, $p = .377$, $\eta_p 2 = .012$; Flow: $F(1, 64) = .67$, $p = .548$, $\eta_p 2 = .006$) or sex (Presence: $F(1, 64) = 53$, $p = .468$, $\eta_p 2 = .008$; Flow: ($F(1, 64) = .37$, $p = .548$, $\eta_p 2 = .006$) were found, as well as no interaction effects of dimensionality vs. sex (Presence: ($F(1, 64) = .02$, $p = .892$, $\eta_p 2 = .000$; Flow: ($F(1, 64) = .01$, $p = .915$, $\eta_p 2 = .000$).

Table 1. F-statistics for sickness, physical condition, presence, and flow.

Analysis	Factors	$F(1,64)$	p	$\eta_p 2$	Sig.
SSQ	Time	14.71	.000	.187	**
	Sex	12.16	.001	.160	*
Oculomotor	Time	20.76	.000	.245	**
	Sex	15.34	.000	.193	**
Disorientation	Time	29.59	.000	.316	**
	Sex	10.53	.002	.141	*
	Time × sex	7.44	.008	.104	*
Heachache	Sex	8.03	.006	.112	*
Pressure	Sex	6.94	.011	.098	*
Eye Burning	Sex	5.74	.020	.082	*
	Sex × dimensionality	4.10	.047	.060	*

Note. ** p < .001; * p < .05.

The majority of the participants (88.2%) had fun during the training, for 2.9% the training was not fun 8.8% had partly fun with the training. There are no group differences between 2D and 3D design ($X^2(2, N = 68) = .50, p = .779$) but more women (33) reported fun during the training than men (27; $X^2(2, N = 68) = 6.6, p = .037$).

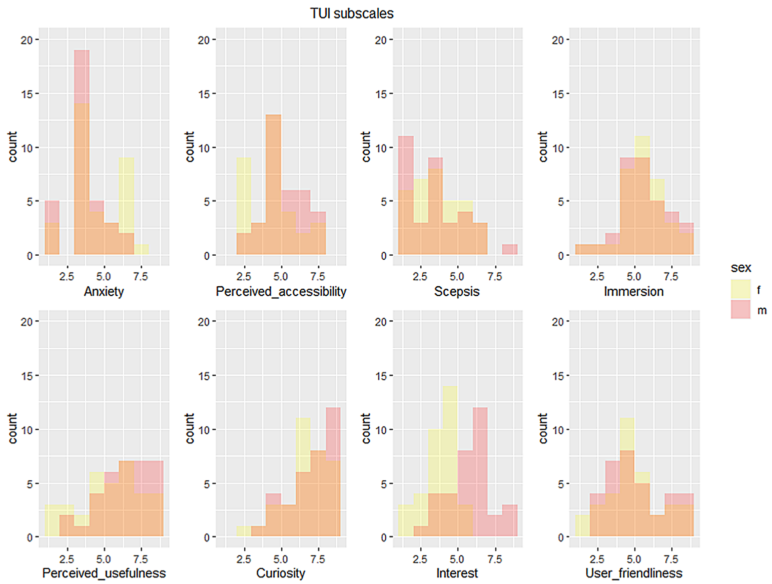

Fig. 2. Histograms of the TUI subscales showing sex differences.

2.6 Discussion

In the present study, the differences of a 3D and 2D VR-NF paradigm on user experience and possible sex differences were evaluated. Participants completed a single EEG-NF session while wearing VR goggles. Here, we found several sex differences in terms of user experience.

Cybersickness was higher after the VR-NF training than before. One previous study on motion sickness in virtual environments reported that subjective sickness values were much higher, when questionnaires were given pre and post exposure to the virtual environment, as if they were only given post-exposure [34]. Hence, asking participants twice might bias their answers to higher sickness values. However, participants from the 3D group did not report higher cybersickness than those, from the 2D feedback. Hence, more dynamic paradigms do not necessarily result in higher values of cybersickness, being applicable in terms of NF interventions.

Women reported higher sickness than men, appearing to be more easily affected by VR training concerning sickness. In fact, such sex-differences can be biologically hard-wired or generated through differences in VR-experiences [4]. Women have a higher field of view [31], there is a greater non-fit of the interpupillary distance of the VR goggles in female participants [27]. Additionally, female hormones increase susceptibility to simulator sickness [13]. Nevertheless, previous studies suggested that VR-experience accounts at least as much as sex to the development of sickness-symptoms [25]. Video-game experience has not been assessed in this study, however, we tried to find different aspects that could represent user experience. Women reported lower levels of subjective accessibility of the technology, which could indicate that the female participants had less VR-experience. Furthermore, women also experience higher technology anxiety than men, which also has been found elsewhere [24]. Trait-anxiety can be a driving factor in the generation of cybersickness [18]. This is an important indicator that participants need to get used to the technology in for example introduction sessions, to secure the best possible training success and reduce anxiety to a minimum.

What is more, women rated the VR technology as less useful. As stated in the Technology Acceptance Model (TAM) of Davis [5], perceived usefulness is a crucial point in the acceptance of technology, entailing a higher intention to use in participants. This implicates that Virtual Reality and its possibilities in usage as well as its possible consequences should be communicated at the beginning of the neurofeedback session more directly to the participants, so that even less-experienced individuals can grasp the usefulness of the used technology. However, women did not have a solely negative user experience. The less perceived accessibility of the technology might be the reason, why women reported more fun during the training as maybe less women previously had the chance to try VR compared to male participants.

No group differences in subjective feeling of presence, however, were apparent between 3D and 2D groups. One reason for that is that even in the 2D group, three dimensional effects could not completely be ruled out. The dark space around the 2D bar target object, evokes a feeling of presence due to the stereoscopic effect of the VR goggles. Also, bigger screens result in higher feelings of presence [10] when using stereoscopic projection screens to display VR scenarios, but in the present study, both paradigms were shown with Virtual Reality goggles, therefore, did not differ in presentation size. They therefore had the same level of immersion which also correlates with presence [16]. Therefore, both groups were very similar in the technical aspects, wherefore no differences in presence could emerge.

Also, no group differences in the subjective flow-experience were found, which was also recorded previously in a NF study comparing a computer screen vs. VR projection screen paradigm [6]. This may be explained by episodes of successful feedback-moments that were too short to lead to a flow sensation. The target object was green and moving into the desired direction only when SMR exceeded, and Beta and Theta remained under the individually pre-defined thresholds. Therefore, sequences where all three factors were in equilibrium were comparably short, so that no feeling of flow could develop.

2.7 Conclusion

User experience in combinational VR-EEG neurofeedback designs differs between male and female participants, showing that instructional sessions for the VR would be beneficial for women to get used to the technology they perceive as less accessible. Additionally, the results show that more immersive 3D paradigms do not cause any more side effects than 2D designs. Generally, one strength in this paper is a comparably big sample size, which is rare in neurofeedback studies, and the moderate to big effect sizes. Hence our results point toward generalizability. Nevertheless, more research on this topic is needed.

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