Validating EEG biomarkers in Virtual Reality and Desktop Flight Training

Evy van Weelden[1], Travis J. Wiltshire[1], Maryam Alimardani[1], Max M. Louwerse[1]
[1]Department of Cognitive Science and AI, Tilburg University, the Netherlands

Introduction

Conventional flight simulators can be bulky, expensive, and resource-intensive. Virtual Reality (VR) provides a cheaper substitute for immersive flight training that may serve as a useful addition to current flight training curricula. Previous research has shown that VR flight training is efficient in knowledge transfer, and consequently can improve VR flight performance (McGowin et al., 2020). In addition to performance improvements, VR training might also be used in combination with measuring the neurophysiology of pilots.

To illustrate, an electroencephalography (EEG) study by Kakkos et al. (2019) provided evidence that VR flight simulations were associated with different functional brain network changes compared to 2D desktop flight simulation. These changes could be attributed to the difference between the fidelity of the two simulators and consequently the required workload from the trainee. According to Kakkos et al. (2019), the alterations found in functional connections of the supplementary motor area (SMA), related to changes in workload, could possibly be associated with visuomotor learning. These findings raise the questions of whether desktop training and VR training are different in terms of workload and subsequent alterations in brain activity, and whether this difference is associated with learning and performance improvements.

Previous literature has already established several biomarkers associated with flight training and flight tasks, including the EEG Engagement Index (Bollock et al., 2019; Dehais et al., 2017; Feltman et al., 2020; Prinzel et al., 2000), and frontal theta power (Borghini et al., 2013). Whereas these metrics have mainly investigated the individual's training level or experienced workload, the impact of the training environment (i.e. fidelity and ecological validity of the simulator) on the trainees' brain activity, performance and learning gains remains unknown.

The current study aims to address this gap by comparing EEG biomarkers of two flight simulation environments that differ on level of immersion, namely VR vs. Desktop. The aforementioned EEG biomarkers of workload and training level are evaluated and their relationship with task performance and subjective workload in each environment are examined. This information can be used to model learning and training impact of flight simulations across novices in future research.

Proposed Methodology

Participants and Procedures

A priori power analysis showed that a sample size of N = 45 was needed to detect effects between conditions (G*Power; Faul, Erdfelder, Lang & Buchner, 2007). Thus, we aim to recruit 45-50 healthy participants in this study, who will participate in both conditions in a within-subject experimental design (fidelity condition: Desktop vs. VR). The experimental procedure is outlined in Fig. 1A.

Experimental sessions are preceded with a pre-experiment questionnaire to inquire gaming and VR experience, age, gender and handedness of participants. In each condition, the following questionnaires are administered to obtain subjective measures of workload, usability and presence: the Simulator Sickness Questionnaire (SSQ; Kennedy, 1993), the ITC-Sense of Presence Inventory (ITC-SOPI; Lessiter et al., 2001), the NASA Task Load Index (NASA-TLX; Hart & Staveland, 1988), and the Simulation Task Load Index (SIM-TLX; Harris, Wilson & Vine, 2020). These questionnaires could provide convergent validity to our methods and the EEG biomarkers.

Apparatus
Experiments are conducted in DCS World (Eagle Dynamics, Switzerland) flight simulation (Fig. 1B), or a related simulation package. Flight performance measures, i.e. deviations from given altitude, pitch, airspeed and roll parameters, can be measured using Tacview Advanced software (RAIA SOFTWARE INC., Canada) that automatically records telemetry from DCS World. Participants control the simulated aircraft using a throttle (Pro Throttle, CH Products, USA) and joystick (Extreme 3D Pro, Logitech, Switzerland). The Oculus Rift S (Facebook Technologies, LLC; USA) is used during the VR condition. A wireless 32-channel EEG system (g.Nautilus, g.tec medical engineering GmbH, Austria) is used to record brain activity during the flight tasks.

Data Processing and Analysis
First, EEG spectral powers in theta (4-8 Hz), alpha (8-13 Hz) and beta (13-22 Hz) frequency bands are extracted and then the EEG Engagement Index is calculated using Equation 1 (Freeman et al., 2000) for all subjects.

$$EEG\ Engagement\ Index = \frac{\beta}{\alpha + \theta} \qquad (1)$$

The EEG Engagement Indices and theta band powers will be compared between VR and Desktop conditions. Subsequently, correlation analysis will be conducted between subjective workload measures (obtained by NASA-TLX and SIM-TLX questionnaires) and the EEG biomarkers.

Significance of Research
The outcomes of this research will contribute to neuroergonomics and aviation training research by (1) validating the use of EEG biomarkers of engagement and workload during flight tasks; (2) determining the effect of simulator fidelity on workload, learning, and subsequent brain activity, with the use of EEG biomarkers; (3) introducing potential adjustment of existing training curricula to become more efficient and cost-effective using VR; and specifically (4) enabling development of an adaptive VR training that provides personalized feedback on the basis of EEG data. Accordingly, this research will aid in the improvement of personalized learning for novice pilots.

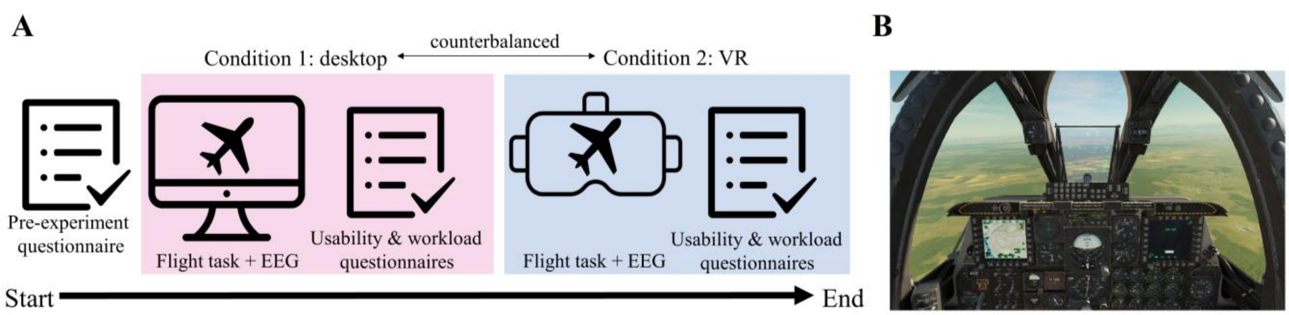

Figure 1. (A) Experimental procedure. Each participant performs two flight tasks in a randomized order: one flight task is performed on desktop computer, and the other flight task is performed with the use of a VR head-mounted display (HMD). The flight tasks are to (1) climb to a given altitude parameter (5,000 ft above sea level) at 300 kts airspeed, and (2) to remain at a given roll parameter (30° roll) while remaining at 4,000 ft altitude. Each task takes 15 minutes, preceded with a 2-min habituation phase. During habituation, participants are instructed to look around in the virtual environment, but are not able to interact with it and control the aircraft. (B) Screenshot from DCS World flight simulation. The environments in- and outside of the simulated cockpit are visible.

References:

Bollock, N. K., & O'Brien, M. P., & Gai, Y., & Belt, S. M. (2019, June). *Evidence-Based Training and Adaptive Control: Exploring the Cognitive and Neural Processes and the Interface between the Pilot and Flight Control Systems (Work in Progress)* [Paper presentation]. 2019 ASEE Annual Conference & Exposition, Tampa, Florida. https://www.doi.org/10.18260/1-2--32770

Borghini, G., Aricò, P., Astolfi, L., Toppi, J., Cincotti, F., Mattia, D., ... & Babiloni, F. (2013, July). Frontal EEG theta changes assess the training improvements of novices in flight simulation tasks. In *2013 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)* (pp. 6619-6622). IEEE. https://www.doi.org/10.1109/EMBC.2013.6611073

Dehais, F., Roy, R. N., Durantin, G., Gateau, T., & Callan, D. (2017, July). EEG-engagement index and auditory alarm misperception: an inattentional deafness study in actual flight condition. In *International Conference on Applied Human Factors and Ergonomics* (pp. 227-234). Springer, Cham. https://www.doi.org/10.1007/978-3-319-60642-2_21

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175-191.

Feltman, K. A., Bernhardt, K. A., & Kelley, A. M. (2020). Measuring the Domain Specificity of Workload Using EEG: Auditory and Visual Domains in Rotary-Wing Simulated Flight. *Human Factors.* https://www.doi.org/10.1177/0018720820928626

Freeman, F. G., Mikulka, P. J., Scerbo, M. W., Prinzel, L. J., & Clouatre, K. (2000). Evaluation of a psychophysiologically controlled adaptive automation system, using performance on a tracking task. *Applied Psychophysiology and Biofeedback*, *25*(2), 103-115. https://www.doi.org/10.1023/A:1009566809021

Harris, D., Wilson, M., & Vine, S. (2020). Development and validation of a simulation workload measure: the simulation task load index (SIM-TLX). *Virtual Reality*, *24*(4), 557-566.

Hart, S. G. & Staveland, L. E. (1988) Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock and N. Meshkati (Eds.) *Human Mental Workload*. Amsterdam: North Holland Press.

Kakkos, I., Dimitrakopoulos, G. N., Gao, L., Zhang, Y., Qi, P., Matsopoulos, G. K., ... & Sun, Y. (2019). Mental workload drives different reorganizations of functional cortical connectivity between 2D and 3D simulated flight experiments. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 27*(9), 1704-1713. https://www.doi.org/10.1109/TNSRE.2019.2930082

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, *3*(3), 203-220.

Lessiter, J., Freeman, J., Keogh, E., & Davidoff, J. (2001). A cross-media presence questionnaire: The ITC-Sense of Presence Inventory. *Presence: Teleoperators & Virtual Environments*, *10*(3), 282-297.

McGowin, G., Xi, Z., Newton, O. B., Sukthankar, G., Fiore, S. M., & Oden, K. (2020, December). Examining Enhanced Learning Diagnostics in Virtual Reality Flight Trainers. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 64, No. 1, pp. 1476-1480). Sage CA: Los Angeles, CA: SAGE Publications.

Prinzel, L. J., Freeman, F. G., Scerbo, M. W., Mikulka, P. J., & Pope, A. T. (2000). A closed-loop system for examining psychophysiological measures for adaptive task allocation. *The International journal of aviation psychology*, *10*(4), 393-410. https://www.doi.org/10.1207/S15327108IJAP1004_6