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## Neural Markers of Situation Awareness - Mobile Brain/Body Imaging in Dynamic 3D Environments

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**14. ABSTRACT**  
A virtual reality environment to test situation awareness with varying difficulty levels of predictability, visibility, and stimulus distinguishability was created. 32 data sets with electroencephalography (EEG), eye tracking, and motion capture were recorded and analyzed. A poster was published on the Human Factors and Ergonomics Society Europe Conference (HFES Europe) in Nantes, France. Predicting the performance of the participant using measures of motion capture and eye gaze alone is a promising option. Analyzing the working memory load and cognitive reaction to stimuli based on EEG is ongoing. In order to shed light on important aspects of processing the mobile EEG data, an investigation titled "Identifying key factors for improving ICA-based decomposition of EEG data in mobile and stationary experiments" was published open access in the European Journal of Neuroscience (Klug & Gramann, 2020). Four master students graduated in the project, three master students are currently working in it. Additional publications on data processing, and behavioral and EEG analysis are ongoing.

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**“Neural Markers of Situation Awareness – Mobile Brain/Body Imaging in Dynamic 3D Environments”**

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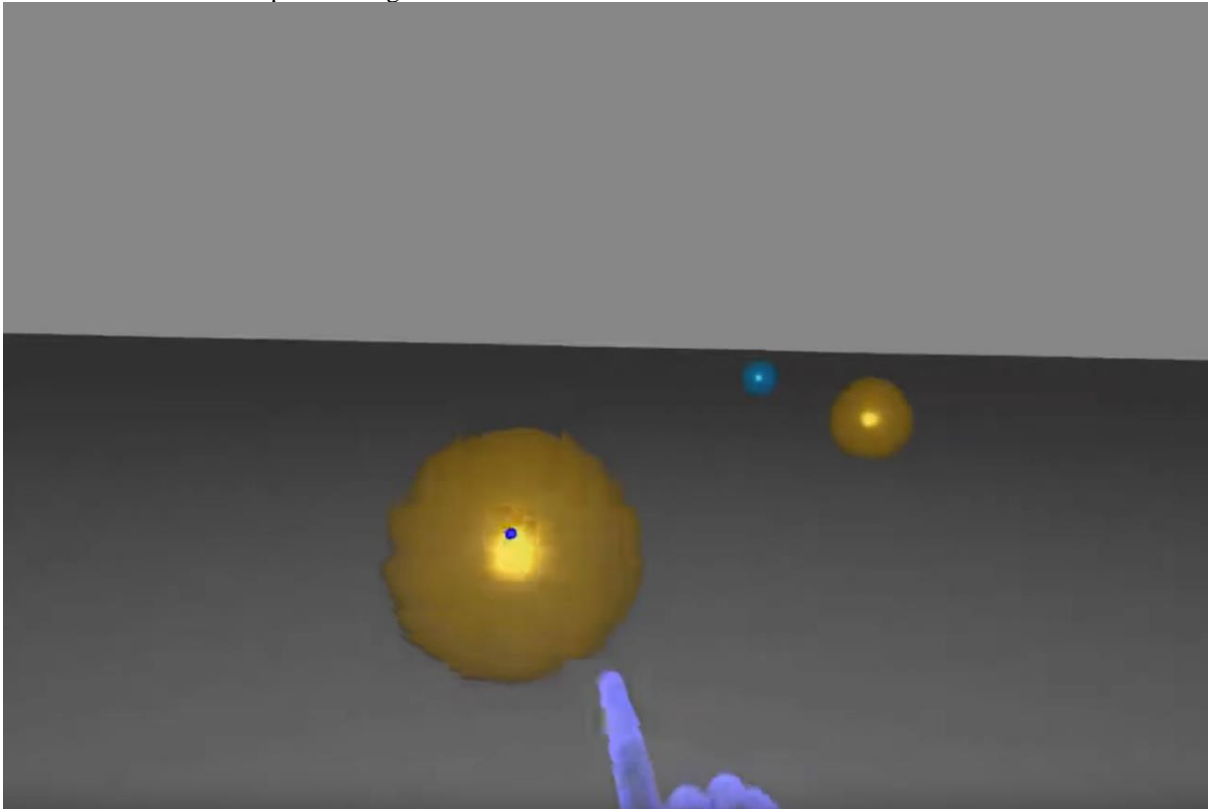
**Abstract:** A virtual reality environment to test situation awareness with varying difficulty levels of predictability, visibility, and stimulus distinguishability was created. 32 data sets with electroencephalography (EEG), eye tracking, and motion capture were recorded and analyzed. A poster was published on the Human Factors and Ergonomics Society Europe Conference (HFES Europe) in Nantes, France. Predicting the performance of the participant using measures of motion capture and eye gaze alone is a promising option. Analyzing the working memory load and cognitive reaction to stimuli based on EEG is ongoing. In order to shed light on important aspects of processing the mobile EEG data, an investigation titled “Identifying key factors for improving ICA-based decomposition of EEG data in mobile and stationary experiments” was published open access in the European Journal of Neuroscience (Klug & Gramann, 2020). Four master students graduated in the project, three master students are currently working in it. Additional publications on data processing, and behavioral and EEG analysis are ongoing.

**Introduction:** The aim of this project is to investigate human brain dynamics underlying situation awareness in actively behaving participants. The project goals are i) to develop a Virtual Reality (VR) platform for testing perception, comprehension, and prediction aspects of Situation Awareness (SA) and ii) to investigate brain dynamic features that reflect them.

**Experiment:**

In order to investigate situation awareness in a controlled and mobile fashion, a virtual reality (VR) environment was created using the Unity 3D game engine. The participant is situated on a grey floor, target and distractor spheres (as indicated by sphere color) of 50cm size spawn, and float towards the participant. Target spheres have to be touched, distractor spheres have to be avoided. Using a configuration file, parameters like sphere spawning distance, speed, color and spawn timings can be changed in order to create blocks of varying difficulty levels and different types of difficulty. The

virtual environment is depicted in figure 1.



*Figure 1: Virtual Environment. Spheres float towards the participant, target spheres (here in yellow) need to be touched, distractor spheres (blue) avoided. The blue dot represents the eye gaze of the participant and was hidden to the participant.*

Furthermore, a virtual version of the NASA Task Load Index (NASA-TLX) and the Situation Awareness Rating Technique (SART) questionnaire was created which can be administered and answered within VR. The virtual environment additionally makes use of the SensoMotoric Instruments eye tracking software development kit to allow measurement of eye gaze and pupil parameters, and integrates the “LSL4Unity” software package which allows recording motion capture, eye tracking, and experiment events with the LabStreamingLayer (LSL) protocol. Lastly, software to stream high-density (128 channels) electroencephalography (EEG) using the ANT eego sports system to LSL was created. Combined, this setup allows for synchronized multi-modal recordings with EEG, eye tracking, motion capture, and experiment events in a single protocol and a single synchronized resulting data file, greatly facilitating subsequent analysis.

Analogous to the levels of situation awareness (perception, comprehension, projection), task difficulty is manipulated in three different ways: distinguishability (D), predictability (P), and color visibility (V):

- D) Spheres are either colorful ((70,0,±128) in CIELAB color space, blue and yellow), or greyed out ((70,0,±1.2) in CIELAB space).
- P) Spheres either appear regularly with an interstimulus interval (ISI) of 0.75s, all have the same velocity of 4m/s, and all spawn at the same distance of 10m from the center, or they spawn unpredictably with an ISI ranging from 0.5s to 1s, have different velocities ranging from 1.5m/s to 6.5 m/s, and spawn at different distances ranging from 5m to 15m from the center, resulting also in collisions with sudden changes of movement speed (but not direction).
- V) The colors of the spheres are either visible permanently, or replaced with an isoluminant grey and spheres show the actual color only from the time a fixation on the sphere is detected until 200ms after the fixation ended.

These levels were administered in a fully counterbalanced 2x2x2 design with blocks split in two halves, and NASA-TLX and SART measures were taken after each half. Subject well-being was ensured by mandatory breaks. The experiment lasted about 2h per participant, plus time for gelling the EEG and setting up the hardware, altogether the participants spent around 4h in our facilities. The experimental design can be seen in figure 2, and a 10 minute demo video can be found online at <https://youtu.be/z7IBAJvNey4>.

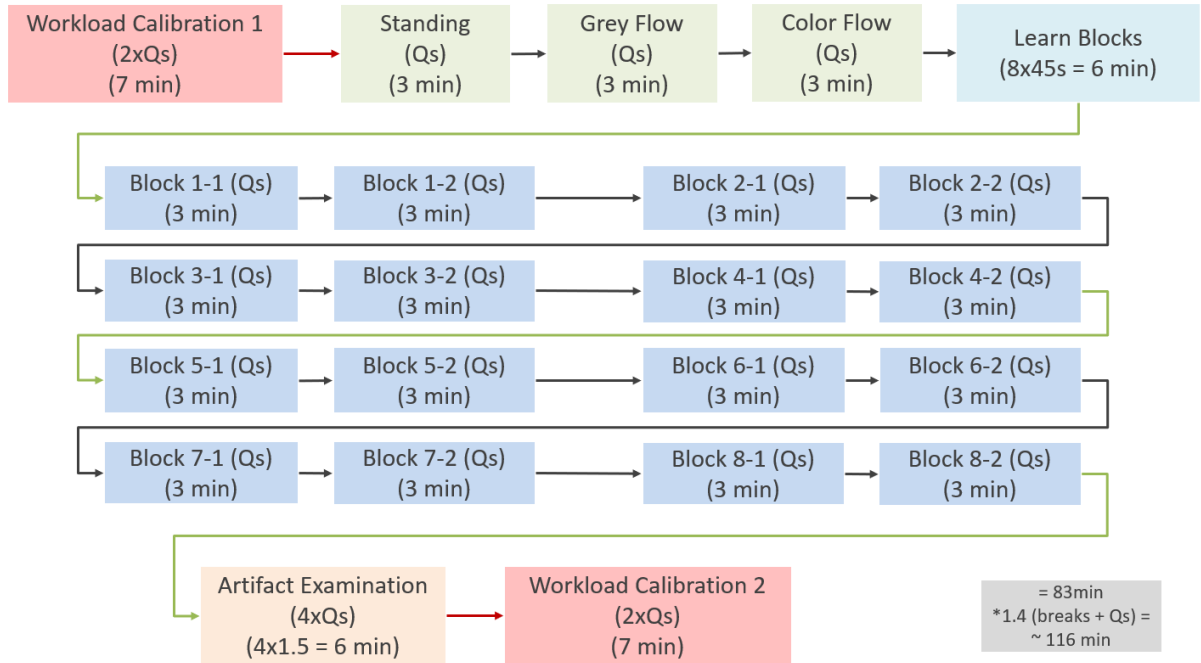


Figure 2: Experimental Design. Red blocks represent a calibration session for a workload classifier (outside of VR), green blocks represent baseline measurements inside VR (without tasks, just observation), light blue blocks represent learn blocks, dark blue blocks represent the experiment blocks, orange blocks represent an additional short examination of movement artifacts. Red arrows indicate a transition to and from VR, green arrows indicate a mandatory break. Qs indicate an administration of questionnaires.

## Results and Discussion:

Figure 3 shows the results of performance (percentage of errors), NASA-TLX, and SART. All three measures were successfully manipulated by the experiment. An expected ceiling effect of performance can be seen when having only one of the three difficulty levels on the difficult setting. We created multiple linear regression with mixed effects models (LMEs) to predict the performance using either the questionnaires or behavioral data from the eye tracker and the motion capture. Figure 4 shows the results of these two models. Using the Akaike Information Criterion (AIC) as an estimate of model likeliness, it can be inferred that the behavior model is a better estimate of performance. This is an important step towards being able to measure and predict task performance continuously using only multimodal objective measurements.

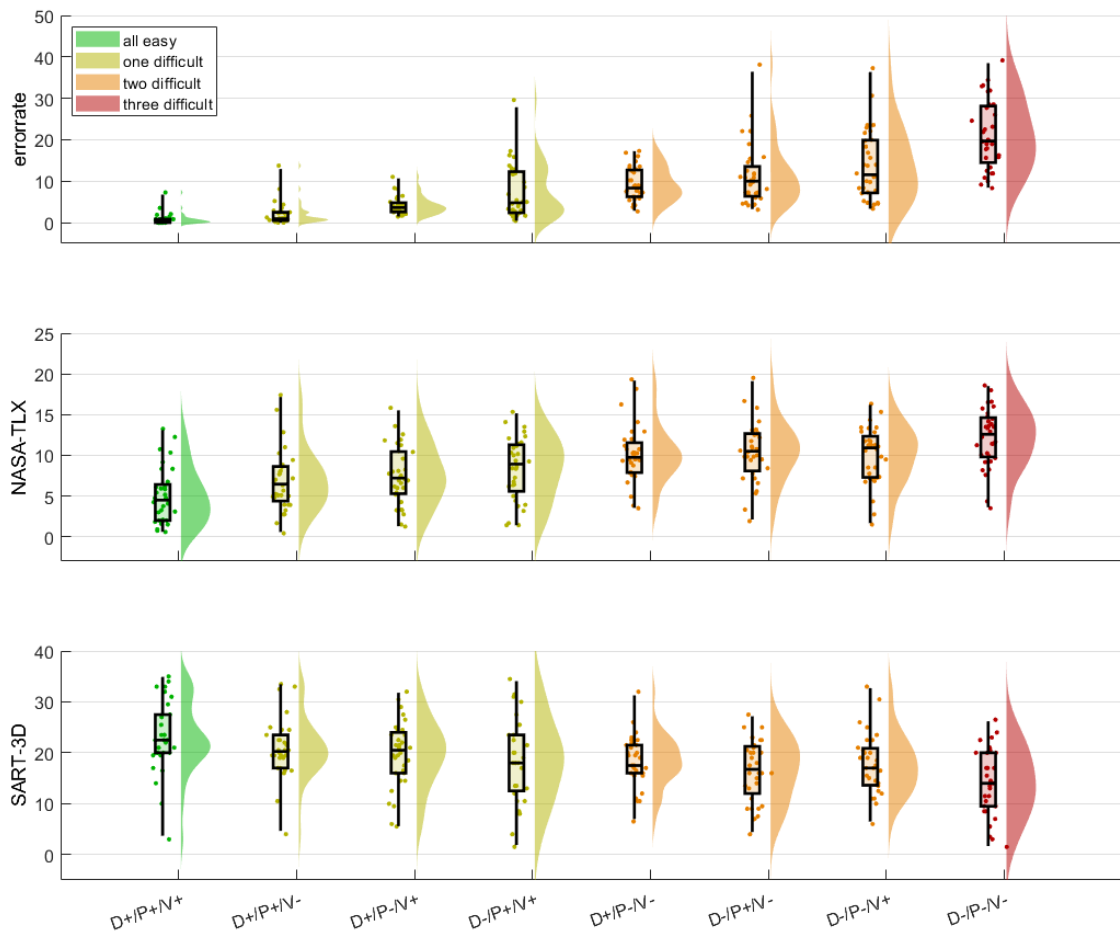


Figure 3: Results of performance (errorrate), as well as the NASA-TLX, and SART questionnaires. The difficulty levels are discriminability (D), predictability (P), and visibility (V), “+” refers to the easy level, “-” to the difficult one.

Analyzing the EEG data present itself as more difficult than anticipated, mostly due to the significant amount of artifacts stemming from the movement during the experiment. In order to better understand the necessary EEG data preprocessing steps to improve the obtained signal of mobile data in the present experiment, an investigation was performed which compared the effect of high-pass filtering (0-4Hz), channel density (16-147 channels), and mobility (stationary/mobile) on the Independent Component Analysis (ICA).

It was found that the factors had an important influence on the number of brain components reconstructed by the algorithm (see figure 5), as well as the signal-to-noise ratio (SNR) and the event-related potential (ERP) waveforms of the cleaned dataset (see figure 6). A higher high-pass filter is necessary in the mobile context. Importantly, even 32 channels or potentially 16 channels are enough to obtain reasonable ERPs, opening the possibility to replicate the present situation awareness experiment with fewer electrodes.

Lastly, preliminary analysis of fixation-related ERPs (FRPs) was performed to understand different cognitive processes when fixating on target and distractors. Figure 7 shows the FRP at the parietal central (Pz) electrode, a statistically significant difference between target and distractor fixation can be found from -100ms to 670ms around the fixation. Importantly, this difference is already present before the stimulus is fixated, suggesting important stimulus processing already while the stimulus is in the visual periphery.

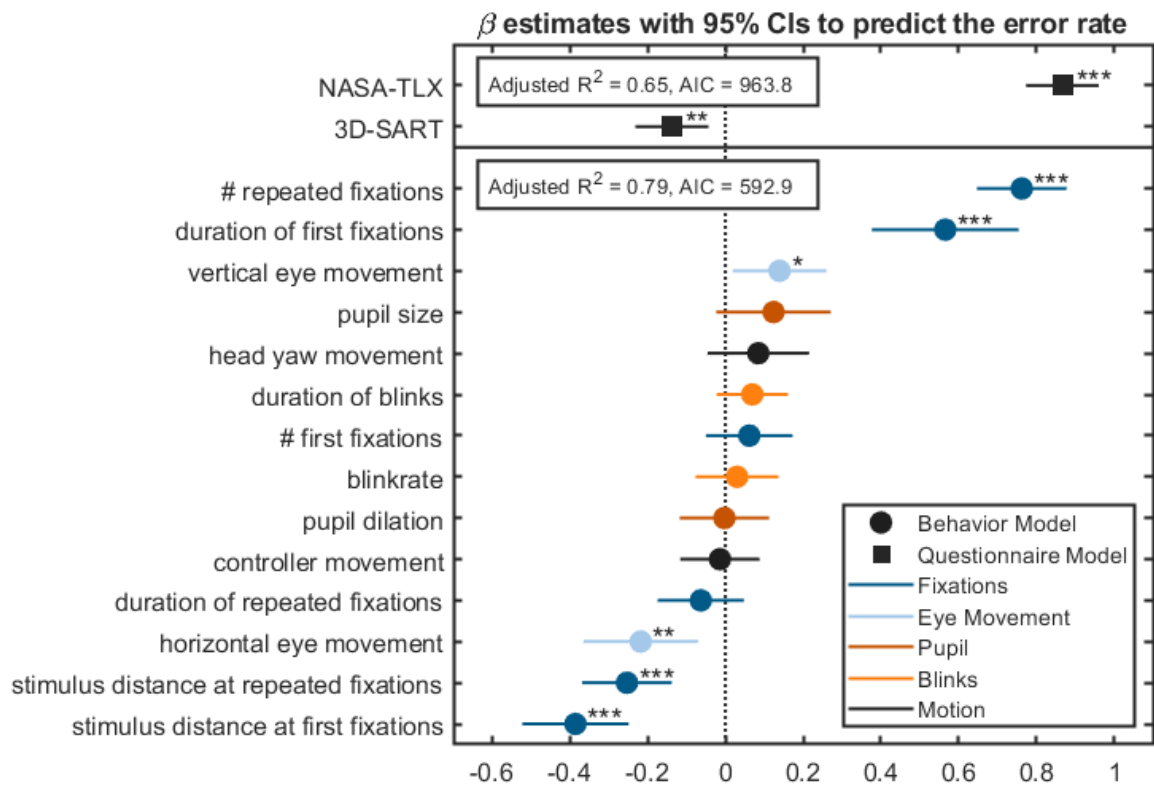


Figure 4: Results of linear mixed effects models to predict performance. The top area refers to the model containing questionnaires as predictors, the bottom area to the model using behavior as predictors. Model coefficient beta weights and 95% confidence intervals are shown for each coefficient. The statistically significant coefficients are marked as such (\* =  $p < .05$ , \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$ ).

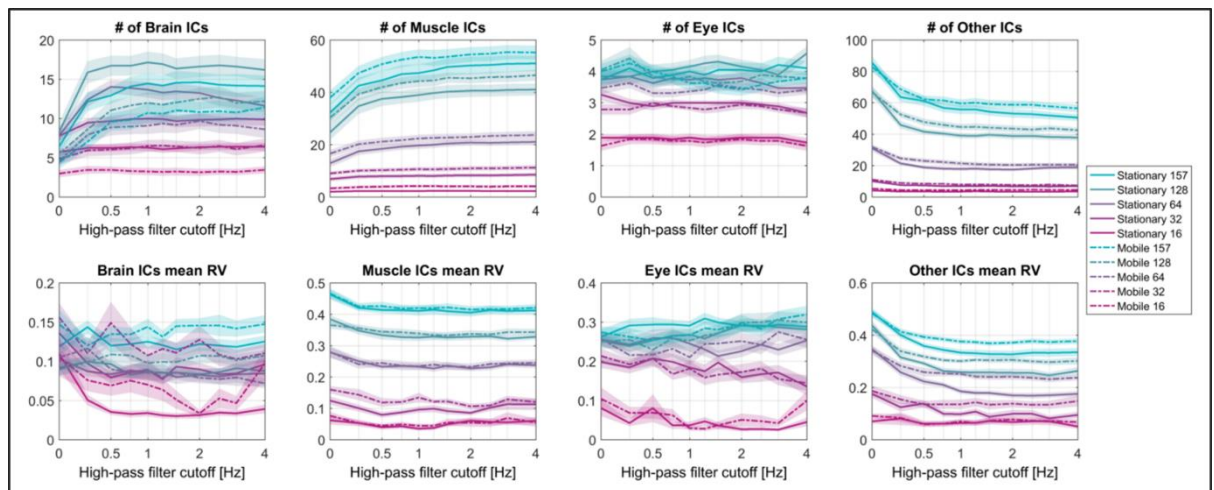


Figure 5: Effect of high-pass filtering, channel density, and participant mobility on the number of brain sources reconstructed by ICA.

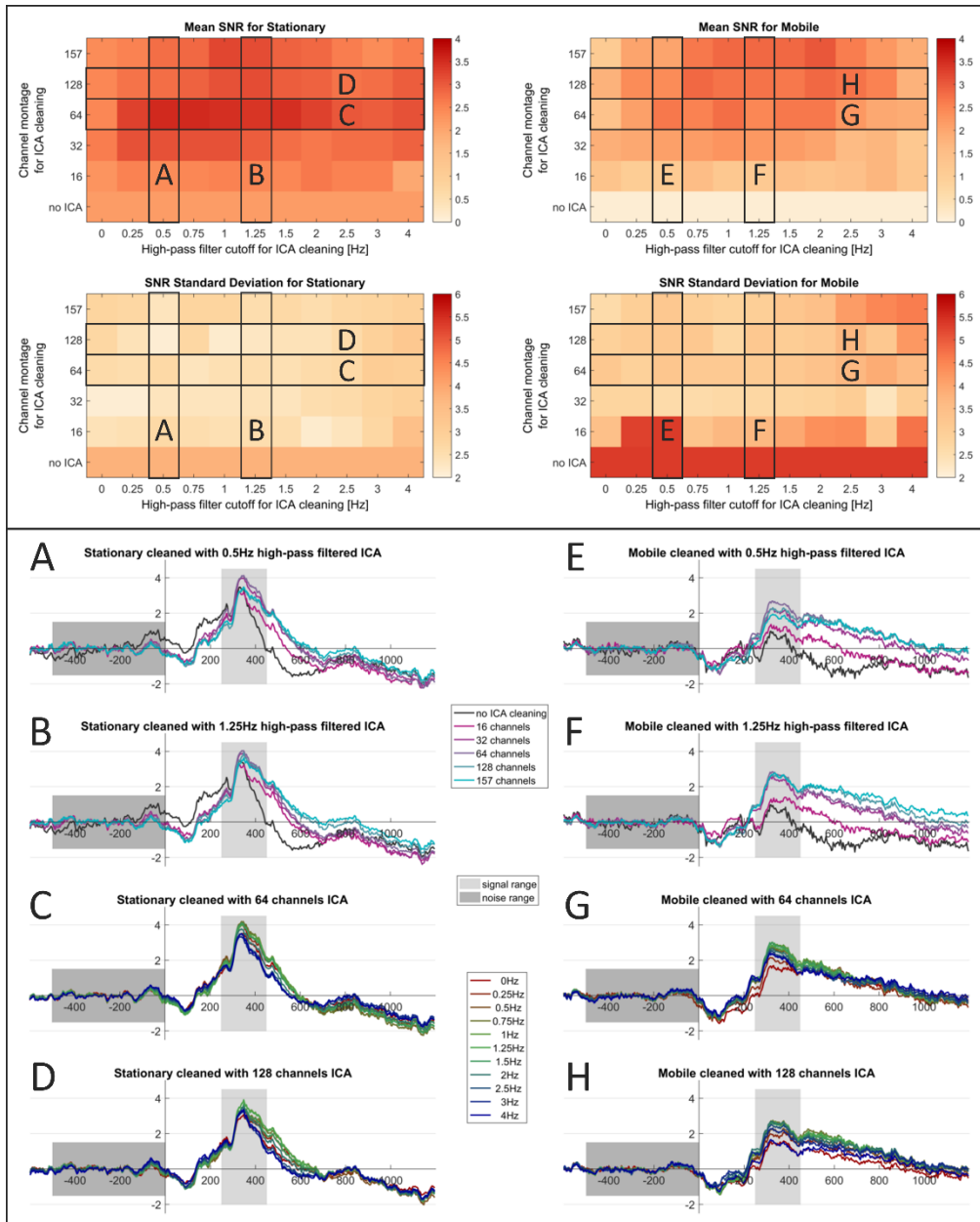


Figure 6: Effect of high-pass filtering, channel density, and participant mobility on the signal-to-noise ratio (SNR) and ERP waveforms when cleaning the data with ICA. Importantly, the ICA results were copied back to the unfiltered data, the ERPs were computed on that unfiltered data after removing all non-brain independent components.

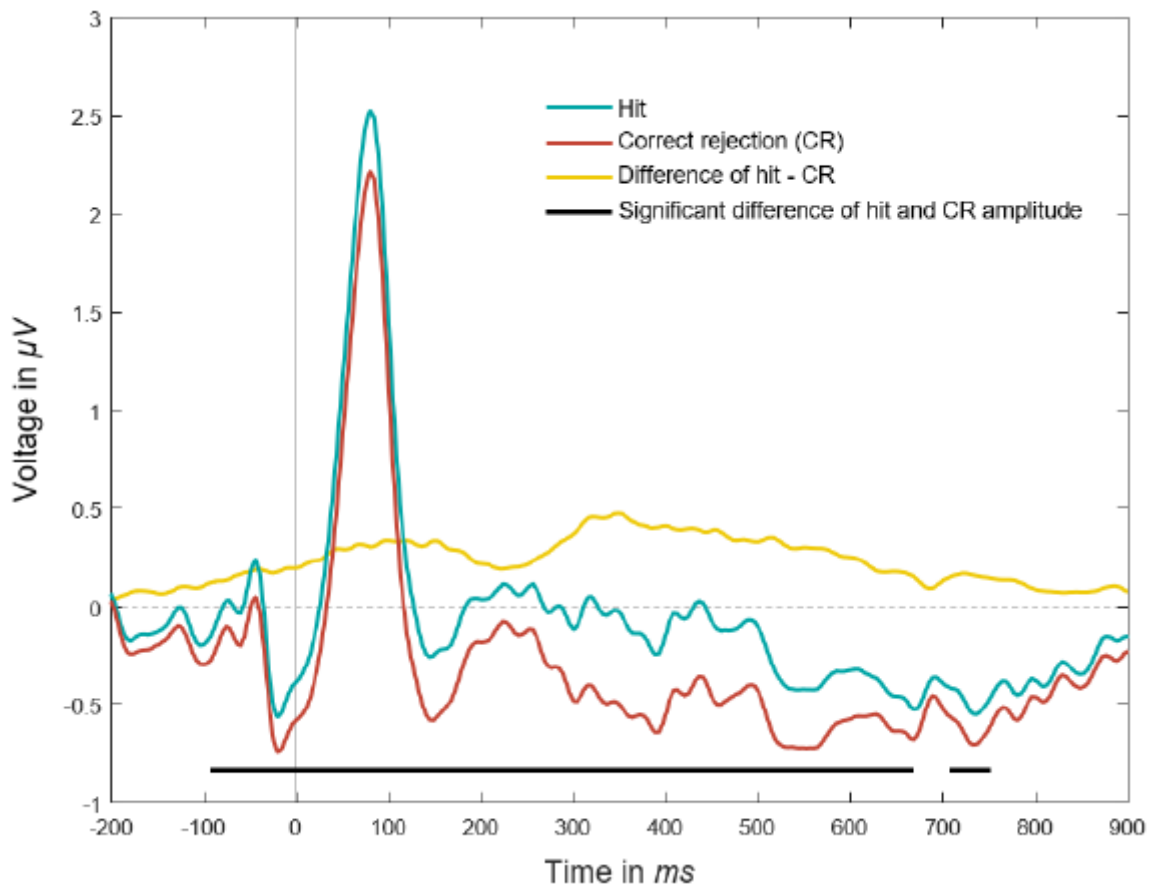


Figure 7: Fixation-related potentials for targets and distractors.

**List of Publications and Significant Collaborations that resulted from your AOARD supported project:** In standard format showing authors, title, journal, issue, pages, and date, for each category list the following:

a) papers published in peer-reviewed journals:

Klug, M., & Gramann, K. (2020). Identifying key factors for improving ICA-based decomposition of EEG data in mobile and stationary experiments. *European Journal of Neuroscience*, May, 1–15. <https://doi.org/10.1111/ejn.14992>

b) papers published in peer-reviewed conference proceedings

Marius Klug, Silvia Pelucchi, Florian Grieb, Lea Rabe, Max Neufeld, & Klaus Gramann, Neuroergonomical Assessment of Situation Awareness in a Virtual Environment (NeSitA), in: D. de Waard, A. Toffetti, L. Pietrantoni, T. Franke, J-F. Petiot, C. Dumas, A. Botzer, L. Onnasch, I. Milleville, and F. Mars (Eds.) (in progress/2020). *Proceedings of the Human Factors and Ergonomics Society Europe Chapter 2019 Annual Conference*. ISSN 2333-4959 (online). Available from <http://hfes-europe.org>

c) papers published in non-peer-reviewed journals and conference proceedings,  
 d) conference presentations without papers,  
 e) manuscripts submitted but not yet published, and

f) provide a list any interactions with industry or with Air Force Research Laboratory scientists or significant collaborations that resulted from this work.

We have met with Maj US Air Force Chad Tossell and a group of cadets on June, 1st, 2018 under the WOS program

Four master students successfully graduated in the project:

- Sven Wehrend  
“Piloting of a situational awareness framework and adaption of an EEG-processing pipeline”
- Silvia Pelucchi  
“Fantastic workload and where to find it: Investigation of the neural correlates of workload in a Situation Awareness paradigm using a mobile Brain/Body Imaging approach”
- Lea Rabe  
“Investigating early and late fixation-related potentials in association with situation awareness in a dynamic, interactive virtual reality experiment”
- Florian Grieb  
“Identifizierung von Prädiktoren für Situation Awareness mittels Eye-Tracker und Motion Capture in VR“

Three master thesis projects are ongoing:

- Max Neufeld (Title TBA)
- Eric Kolibacz (Title TBA)
- Pan Yanzhao (Title TBA)

Two invited talks were given during the project:

- Neural Markers of Situation Awareness in mobile Virtual Reality - An introduction to Mobile Brain/Body Imaging - Institute for Systems Neuroscience, UKE, Martinistr. 52, Hamburg, Germany
- Mobile Brain/Body Imaging and Neuroadaptive Technologies – A perspective on fusing two fields, NAT 2019 Conference (<https://neuroadaptive.org/conference/2019>)

Two conferences were visited:

- Neuroadaptive Technologies (NAT) 2019, invited talk
- Human Factors and Ergonomics Society (HFES) Europe 2019, poster publication

**Attachments:** Publications a), b) and c) listed above if possible.

**DD882:** As a separate document, please complete and sign the inventions disclosure form.