Turbulence impact on EEG and touchscreen vigilance

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Introduction:

Vigilance is a mental state that is significantly affected by neuro-psychological changes such as concentration, fatigue, or sleep deprivation (Luppi and Fort, 2019). It is one of the most important human factors that contribute to air traffic accidents. During air operations, pilots' vigilance may encounter a significant decrease. It can arise from the length of duty periods, working during the circadian low of alertness, and circadian dysrhythmia arising from time-zone change. Other meteorological and atmospheric factors such as turbulences may affect the vigilance state of the pilots. There are varying degrees and types of turbulence caused by upward and downward currents from thunderclouds, thermal currents, or clear air turbulence from rapidly changing wind speed or direction. Clear air turbulence is the most dangerous kind, as it occurs in cloudless skies with perfect visibility. Thus oncoming turbulence cannot be picked up by weather radar which requires a more important state of vigilance and attention.

An important number of functional brain studies focused on neural activity to detect vigilance, fatigue, and drowsy states (Tian et al., 2018). They proposed to detect vigilance based on biomedical signals such as electroencephalogram (EEG), electrocardiogram, electromyogram, and electro-oculogram (EOG). Some studies have used head-nodding-related tasks to detect fatigue and drowsiness; however, vigilance was sometimes incorrectly detected due to the non-realistic explored environment.

The objective of this study is to explore the electro-physiological and behavioral performance of vigilance state during both realistic stable and turbulence environments, the following considerations were taken into account:

- The response time of the participant to hit a target;
- The number of the participant's mistakes of missed hits;
- The EEG activity;

The research is based on the hypothesis that the volatile and unsteady movements caused by turbulence would change the reaction time and would increase the number of mistakes because of the disturbed attention and visual perception

To the best of our knowledge, this is the first investigation that has targeted EEG and alternative EOG (cf. Belkhiria & Peysakhovich, 2021) to discriminate the vigilance state during turbulence. In this preliminary work, we present only EEG and behavioral performance.

Method:

We adapted the Mackworth Clock Test (Mackworth, 1948) to a touchscreen tablet. Each participant (N =5) performed four Mackworth tasks of 5 min duration each, with a pause of a few minutes between tasks. The order of the Mackworth tasks varying for difficulty (Easy vs. Hard) and for environment (Stable vs. Turbulence) were randomized and balanced across participants. The Mackworth had a red dot moving in a circle with intervals varying from 650 ms to 200 ms, corresponding to increasing task difficulty. Participants had to detect the rare jumps of one position by the red dot (targets). Motion platform PS-6TM-1500 (Motion Systems) induced turbulence movements. It corresponded to a random smooth profile along with pitch, roll, and heave dimensions. Participants kept the seatbelt fastened during the turbulences.

Given its high temporal resolution, portability, lightweight and reasonable cost, we measured EEG and EOG signals with Open-BCI Cyton board with dry Drydrote (Neuroelectrics) electrodes. The brain signals were measured from central cortex regions C1, CZ, C2. The alternative EOG was measured using an around-ear set-up to estimate eye movements avoiding visual field obstruction

(Belkhiria and Peysakhovich, 2020). A customized neoprene head cap held electrodes set were further pressed by an aviator headset.
The EEG data were recorded at 250 Hz and processed using EEGLab and Matlab (2019b). An EEG pipeline was used to compute frequency features from continuous EEG (sliding window scheme). Artifact Subspace Reconstruction automatically removed short-time high-amplitudes artifacts. Visual inspection of the preprocessed EEG for each participant was employed after ASR removal.

Figure 1: Adapted touchscreen version of vigilance Mackworth Clock test on the motion platform. EEG and alternative EOG electrodes are placed under an aviation headset.

Results:

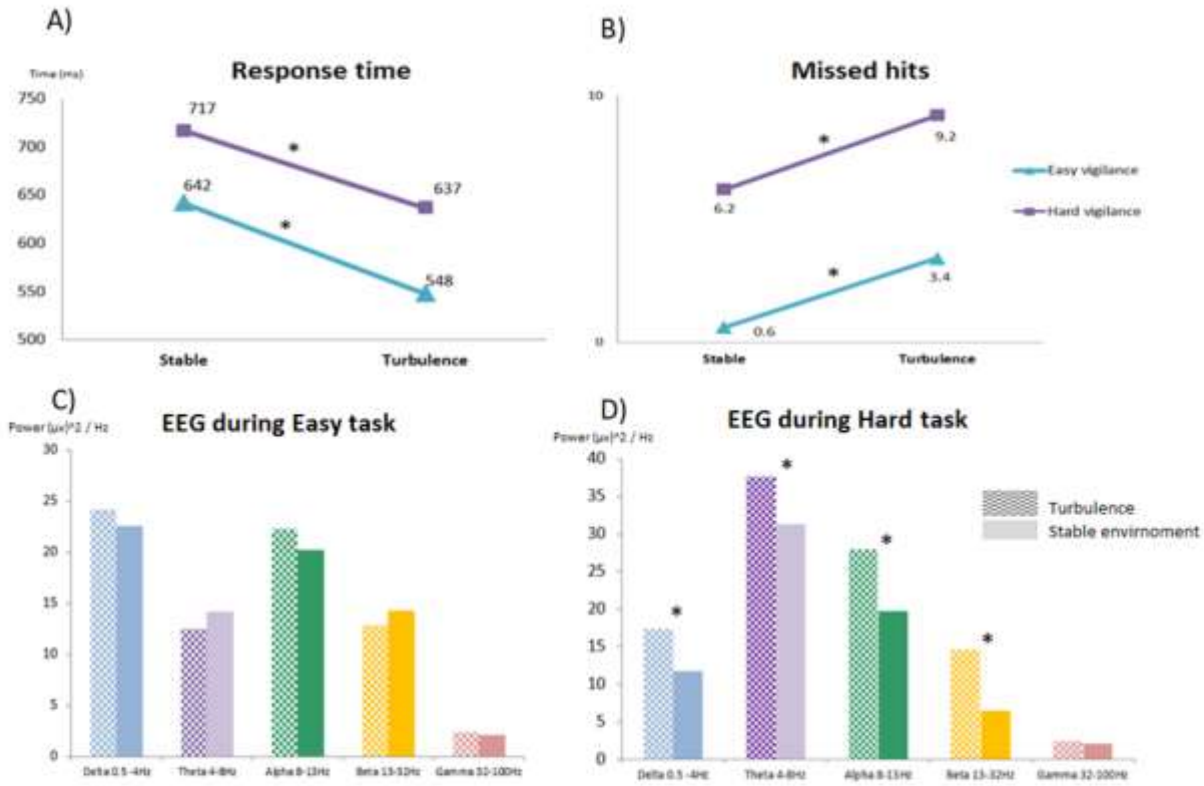

Figure 2: Behavioral performance: Difference between stable and turbulence environments during easy and hard vigilance tasks for Response time (A) and Missed hits (B).
EEG frequencies difference between stable and turbulence environments during easy vigilance task (C) and hard vigilance task (D) for one participant. = $p < 0.05$*

Response time was significantly higher in stable vs. turbulence environment during easy vigilance [$F(2,9)=8.08$, $p=0.02$, $\eta^2=0.02$] and hard vigilance [$F(2,9)=6.02$, $p=0.04$, $\eta^2=0.02$] tasks. The number of missed hits increased during turbulence environment compared to the stable environment during both easy [$F(2,9)=10.88$, $p=0.01$, $\eta^2=0.02$] and hard [$F(2,9)=4.78$, $p=0.05$, $\eta^2=0.06$] vigilances tasks. EEG frequency did not show any significant difference between stable and turbulence environment during the easy task. However, Delta, Theta, Alpha, and Beta frequencies were significantly higher in turbulence vs. stable environment during hard vigilance task ($p < 0.05$).

Discussion and conclusion:

Behavioral results showed that participants were faster when responding to targets in turbulence and missed more targets compared to the stable environment. Response times reflected the speed of the reaction and therefore the environment difficulty: with increasing turbulence and difficulty the response times became increasingly fast. This is an interesting and counter-intuitive effect that shows how the participant spares resources and tends to respond faster when information processing becomes harder and forces him to speed the average response. This suggests that the turbulence effect modulated the attention required to perform the task, which is known as speed-accuracy trade-off (Gueugneau et al., 2017). It is the complex relationship between an individual's willingness to respond slowly and make relatively fewer errors compared to their willingness to respond quickly and make relatively more errors. Our results are in line with a comparable study of touch interaction during simulated turbulence where users were highly error-prone during simulated vibration for touch and trackball targets (Cockburn et al., 2017).

Concerning the EEG frequencies increasing, it represents a crucial mechanism that aims to modulate the allocation of attentional resources necessary for the optimal execution of the task during increasing mental workload. This observation is in agreement with the view that EEG increased in alpha and theta bands in studies that involved visual search tasks, flight simulations, and air-traffic control simulations as well as in working memory load (Borghini et al., 2014). Alpha and theta increasing activity may be associated with concentrative attention engagement as evidence of greater attentional control during turbulence.

The aviator headset has been firmly placed above the electrodes in order to avoid their movements during turbulence. Despite this precaution and the artifacts removal process, the quality of the EEG may still be affected by turbulence. Even though ASR shows great effectiveness in removing large-amplitude artifacts, its limitations and potential solutions should be considered. In the continuity of this study, we will explore how these observed effects in EEG would be extended to alternative EOG. As blinking interferes with sensory processing, we expected a decreasing blink rate with increasing vigilance demand. It would be also interesting to study how the touchscreen tablet can modulate these effects and modify user performance. According to recent innovations, touchscreen interaction in the cockpits of commercial aircraft offers potential advantages to aircraft manufacturers, airlines, and pilots. However, turbulence is still a challenge for their deployment.

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