Impact of Sleep Restriction & Simulated Weightlessness on Speech Perception

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Introduction

- Scientific studies of sleep loss have shown decreases in cognitive abilities, such as sustained attention (Molfese et al., 2013), including slower reaction times, reduced memory, and other executive function deficits (Pilcher & Huffcutt, 1996; Kopasz et al., 2010). These deficits may be caused by sleep loss affecting the prefrontal cortex (Beebe et al., 2009).

- Sleep and cognitive abilities are also impacted by weightlessness. Animal studies (see Adey, 1964), point to degradation of cellular dendrites, caused by increased fluid pressure in the CNS.

- Human studies (Reviews: Christensen & Talbot, 1986; Christensen & Talbot, 1998) noted weightless-related changes in sleep cycles, visual attention, memory, vestibular system, and cognitive abilities. Some deficits were documented using EEG in relation to gravity levels using parabolic flights (Pletser & Quadens, 2003).

- To examine the combination of sleep and weightlessness, we employed a sleep-restriction design alongside simulated weightlessness with a head-down tilt (Lawley et al., 2017), a method adopted by NASA in their own Performance Assessment Workstation (PAWS; Shehab et al., 1998).

Methods

- Seventy-four participants (35f, 39m) aged 30-45 years holding either a MD or PhD were recruited. Prior to data collection, each participant underwent an overnight polysomnographic assessment to screen for sleep abnormalities.

- Participants underwent neuropsychological assessments, and were issued actigraph wristwatch (AW16, MiniMitter-Respironics, Bend, OR), and sleep logs prior to each EEG session.

- Participants were assigned to one of three conditions: (1) Control; (2) sleep reduction of one hour per night; (3) sleep reduction of three hours per night.

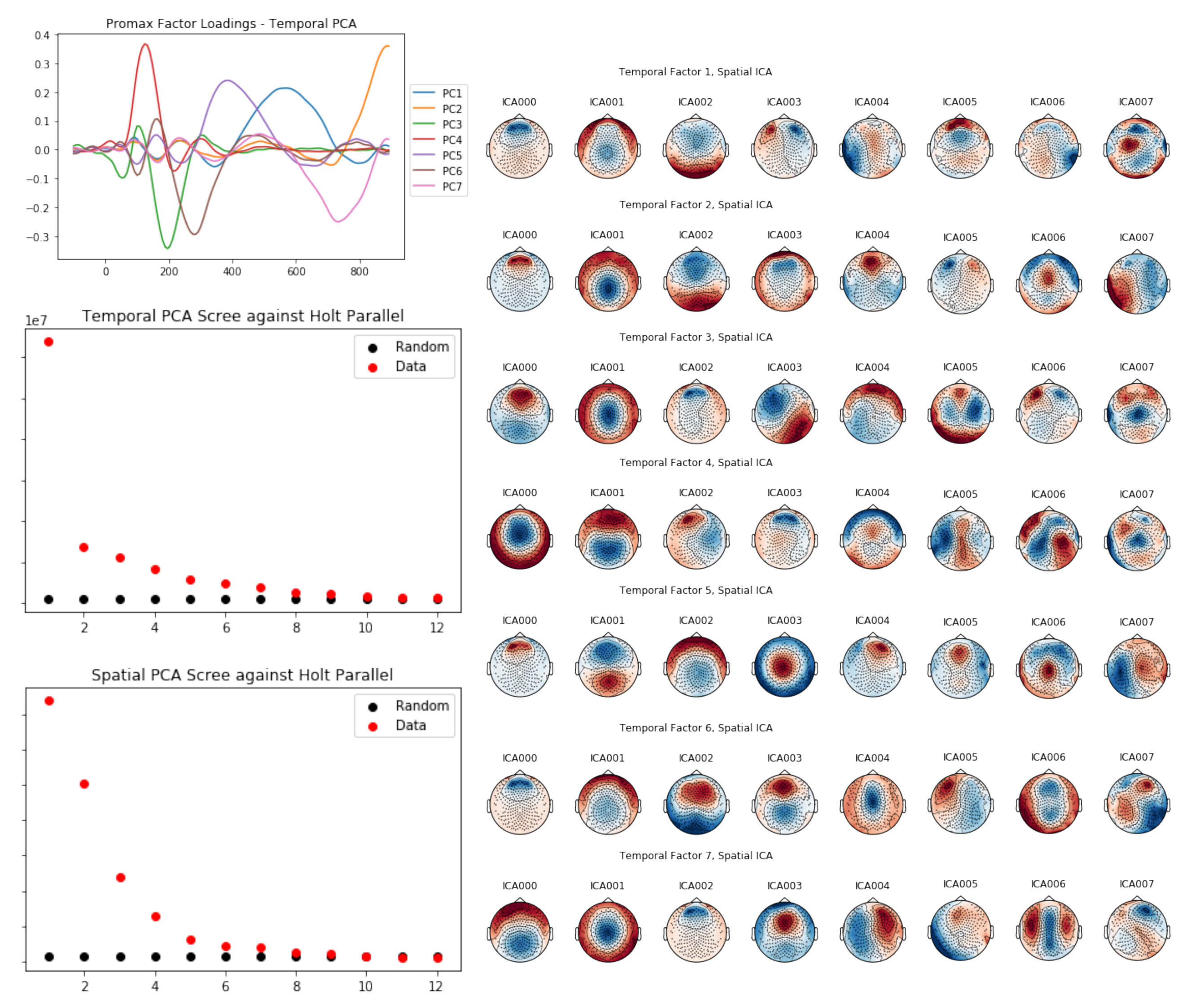
- EEG data were collected using 256-channel geodesic nets (EGI, Eugene, OR) with Ag/AgCl electrodes, prepared in warm saline solution.

- Participants listened to 150 randomized presentations of six computer synthesized consonant-vowel syllables: /ba/,/da/,/ga/,/bu/,/du/,/gu/ during two phases - sitting upright (UP), and in a simulated microgravity head down tilt (HDT).

- Each participant completed this task both seated and at 6-degree head-down tilt.

- Following data collection, EEG signals were filtered to 30Hz, segmented to epochs, checked for artifacts, baseline corrected, re-referenced to the average reference, and averaged into like categories. A temporal spatial-PCA was fitted to the data using Python code replicating the ERP PCA toolkit (Dien, 2010).

PCA Fit Parameters



Results

- The PCA resulted in 7 temporal factors (TF), and 8 spatial factors (SF).

- Adaptive Mean Amplitude with width of 12 milliseconds was calculated using temporal windows with loadings about 0.2 and spatial windows above 0.4

- Each temporal-spatial combination was submitted to a 3 (Group: Control vs. 1-hr restriction vs. 3-hr restriction) X 2 (sleep week) X 2 (position: head-down [HDT] vs. upright [UP]) X 6 (consonant) repeated-measures ANOVA. All results were corrected using Greenhouse-Geisser.

- 22 temporal-spatial factors accounted for more than 2% of variance (more than a single subject's data) and were examined further.

- While no components included a main effect of group, 16 components included a group interaction with another factor.

- Condition effects or interactions with conditions were found in 12 components.

- Stimulus effects or interactions involving stimulus type were found in 18 components.

- Sleep week effects or interactions involving sleep week were found in 17 components.

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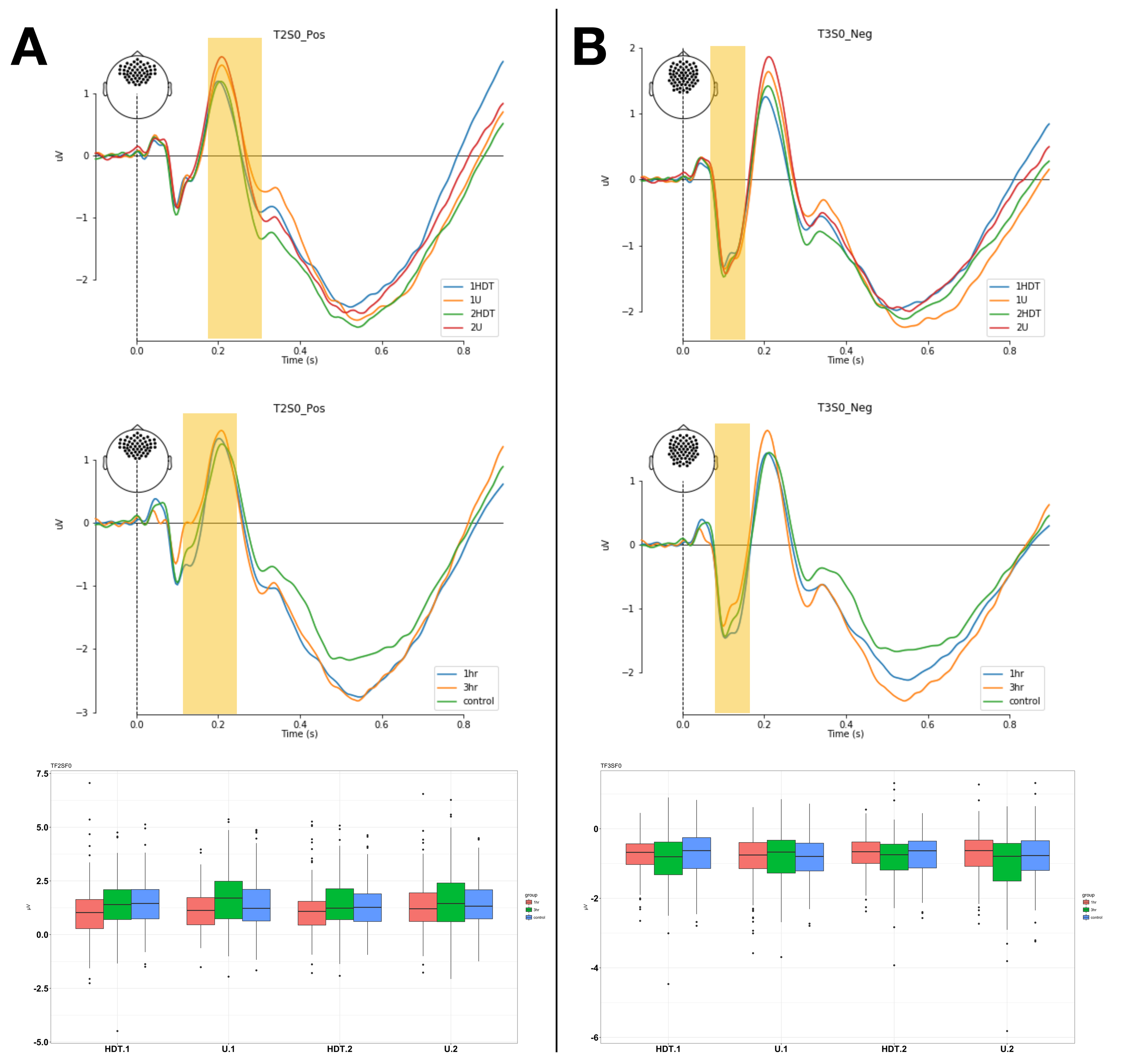
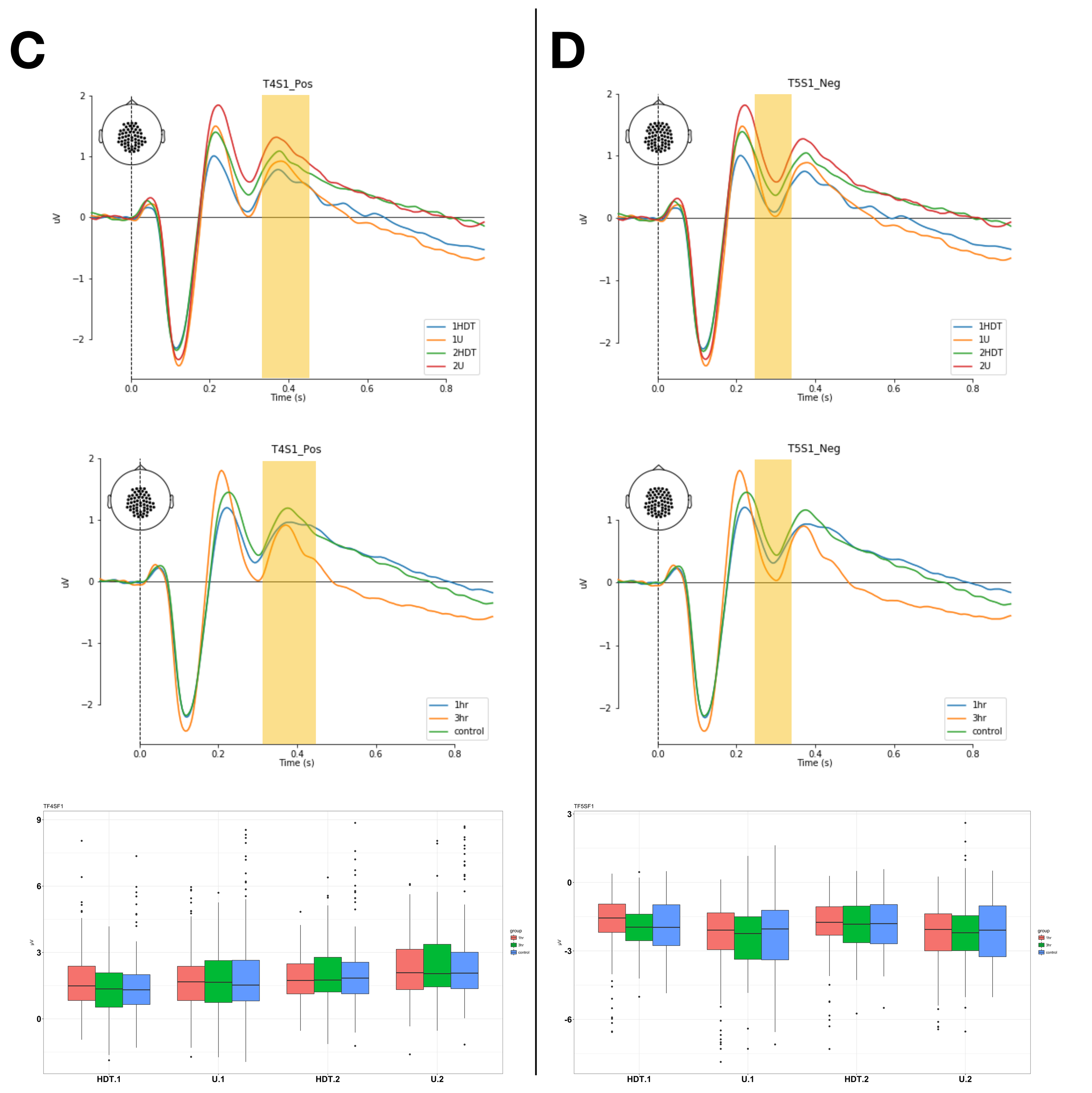
Group Effects and Interactions



Temporal Factor 2, Spatial Factor 0 (A, left) was most active over the window of 164-228 milliseconds post stimulus onset. Electrodes with a positive loading above 0.4 identified an interaction of group X sleep week X stimulus, F(99.23, 332.24)=1.89, p=0.05. A main Effect of stimulus was also found, F(4.32, 311.37)=2.47, p=0.04.

Temporal Factor 3, Spatial Factor 0 (B, right) was most active over 92-156 milliseconds post stimulus onset. Electrodes with a negative loading identified a significant interaction of sleep week X condition X stimulus, F(4.24, 305.5)=2.31, p=0.05, as well as a group X sleep week X condition F(2, 72)=3.93, p=0.02.



Temporal Factor 4, Spatial Factor 1 (C, Left) was most active over 348-436 milliseconds post stimulus, and identified a significant interaction of group X sleep week X stimulus, F(8.5, 306.18)=2.60, p=0.008. Main effects were also found for: sleep week - F(1,72)=55.83, p<.0001, condition - F(1,72)=33.51, p<.0001, and stimulus - F(4.52, 325.13)=5.20, p=0.0002.

Temporal Factor 5, Spatial Factor 1 (D, Right) was most active over a window of 244-316 milliseconds post stimulus. This factor identified an interaction of group X sleep week X condition X stimulus, F(9.35,336.49)=1.87, p=0.05. Main effects were also found for sleep week - F(1,72)=24.42, p<.0001, condition - F(1,72)=4.11, p=0.05, and stimulus - F(4.58,329.87)=5.58, p=0.0001.

Conclusions

Cognitive changes due to sleep loss are seen as early as 92 milliseconds, with effects of simulated microgravity effects around 348 ms. These results illustrate the complex and cascading impact of sleep deprivation and simulated microgravity on the brain's ability to perform even simple tasks.

Future Directions

- The implications of sleep loss on language perception are important, yet it remains to be seen how higher-level cognitive functions (e.g. attention) are impacted by sleep reduction.

- It is unclear how long the impact of sleep restriction continues, a systematic study of a return to baseline function after sleep returns to normal would provide insights into the long-lasting impacts of sleep loss.

- Multi-step PCA is a powerful tool for realizing effects in ERP data

- However the number of temporal-spatial components with oft-similar results introduces questions of the most efficient methods for correcting for multiple comparisons while realizing the usefulness of data-driven analysis methods.

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