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EEG in Dual-Task Human-Machine Interaction:

Target Recognition and Prospective Memory

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Introduction

Studies investigating dual-task performance [4, 1] or retrieval of prospective memory (PM) and configuration of PM tasks [1, 9] gave insight into the capabilities of the brain to perform tasks in parallel and to switch between tasks [1]. However, most experiments are conducted under controlled conditions. Here, we investigate electroencephalographic (EEG) activity recorded under natural conditions during human-machine interaction (HMI) that can be used to passively support the human [2] in multi-task situations, e.g. telemanipulation of robotic systems and mission control [5]. For this passive support, the success of information processing can be predicted with the help of single-trial EEG analysis and classification [7]. A successful execution of multiple tasks requires an efficient strategy of attention division, the detection and evaluation of important, task-relevant information, retrieval of intended action from long-term memory, post-retrieval monitoring, and task-coordination processes characterized by several overlapping event-related potentials (ERPs) [9]. The goal of the study was to investigate the effect of multi-task conditions on positive parietal ERP components evoked by infrequent task-relevant and task-irrelevant stimuli.

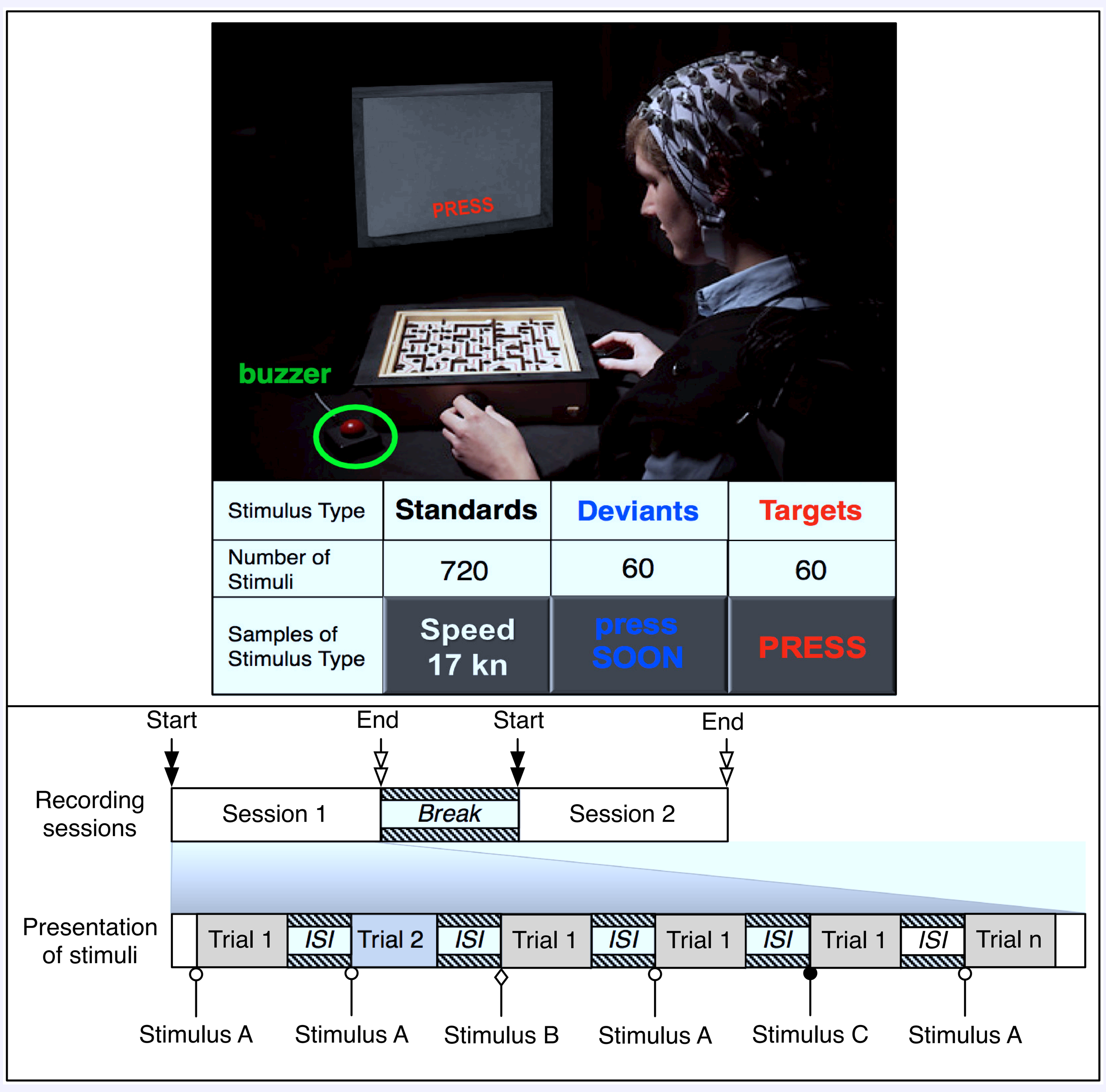
Methods

Experimental Design: Thirteen subjects (age: 27 to 39 years; right-handed; normal or corrected-to-normal vision; one subject was excluded due to eye artifacts) participated in the experiments (see Fig. 1). Subjects performed two tasks: oddball and labyrinth oddball within two counterbalanced sessions. In each session, subjects performed an oddball task and responded to target stimuli (randomly mixed among frequent standard and rare deviant stimuli with a ratio of 1:12:1 and an ISI of 900 and 1100 ms) by pressing a buzzer. During the oddball condition, subjects were asked to hold both knobs of the labyrinth game while focusing on a ball placed in the middle of the game board; whereas during the labyrinth oddball condition, they were requested to play the game.

Data Recording: EEG was recorded with a 64-channel actiCap system (extended 10-20 system; reference at FCz; impedance below 5 kΩ; digitized with 2500 Hz by two 32-channel BrainAmp DC amplifiers [Brain Products GmbH, Munich, Germany]; filtered between 0.1 Hz to 1000 Hz). The averaged data was analyzed by repeated measures ANOVA with "stimulus type" (standards, targets, deviants), "electrode location" (Fz, Cz, Pz), and "time window" (350-600 ms vs. 600-850 ms) as within-subjects factors and "condition" (labyrinth oddball and oddball) as between-subjects factor. If necessary, Greenhouse-Geisser correction, and for pairwise comparisons, Bonferroni corrections were applied.

EEG Analysis: EEG was re-referenced to an average reference and filtered between 0.2 Hz and 30 Hz. Segments from 100 ms before to 1000 ms ms after stimulus onset were averaged based on stimulus of interest (segments containing artifacts were rejected semi-automatically (amplitude 100/-100 μV, gradient 75μV); target epochs required response within 200 to 2000 ms after stimulus onset).

Labyrinth Oddball Scenario



Stimulus Type	Standards	Deviants	Targets
Number of Stimuli	720	60	60
Samples of Stimulus Type	Speed 17 kn	press SOON	PRESS

Figure 1: Experimental Design: Subject performing in the experimental setup (upper part of the figure). Types and number of presented stimuli, session and run design are described in the lower part of the figure.

Results

Reaction time on target stimuli was 0.82 s ($SD = 0.13$) (labyrinth oddball) and 0.79 s ($SD = 0.79$) (oddball). The observed positive broad ERP complex at parietal sites is depicted in Fig. 2. For both conditions we found a maximum in amplitude difference between the ERP form on target versus standard and deviant versus standard stimuli at electrode "Pz" [labyrinth oddball: $p < 0.001$, oddball: $p < 0.001$] (late positivity effect). For the early window, the late positivity effect on targets was under both conditions bigger than the late positivity effect on deviants [labyrinth oddball condition: $p < 0.001$, oddball condition: $p < 0.001$]. However, for the late window, a bigger late positivity effect on targets was only observed in the labyrinth oddball condition [labyrinth oddball condition: $p < 0.049$, oddball condition: $p = n.s.$].

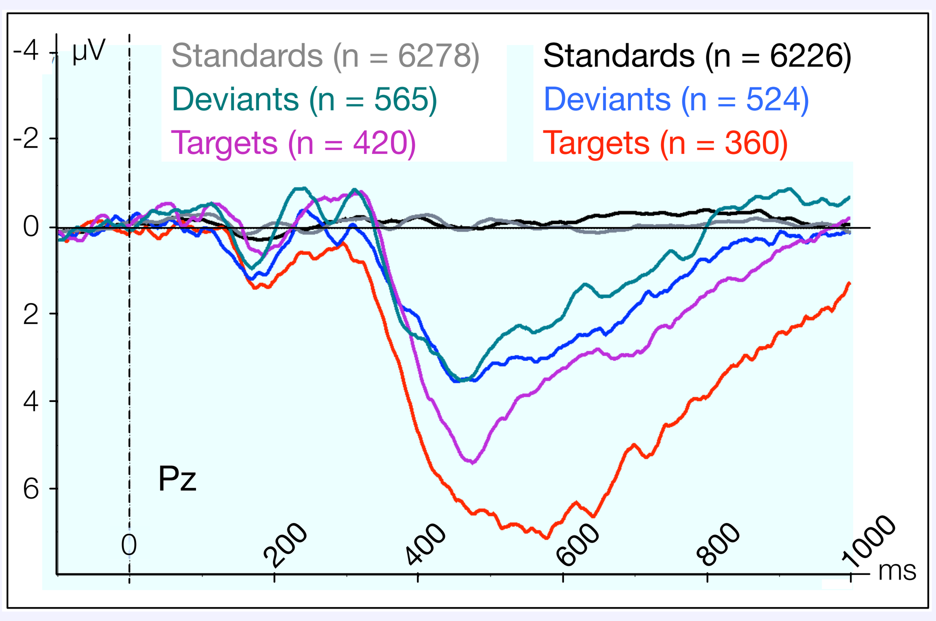
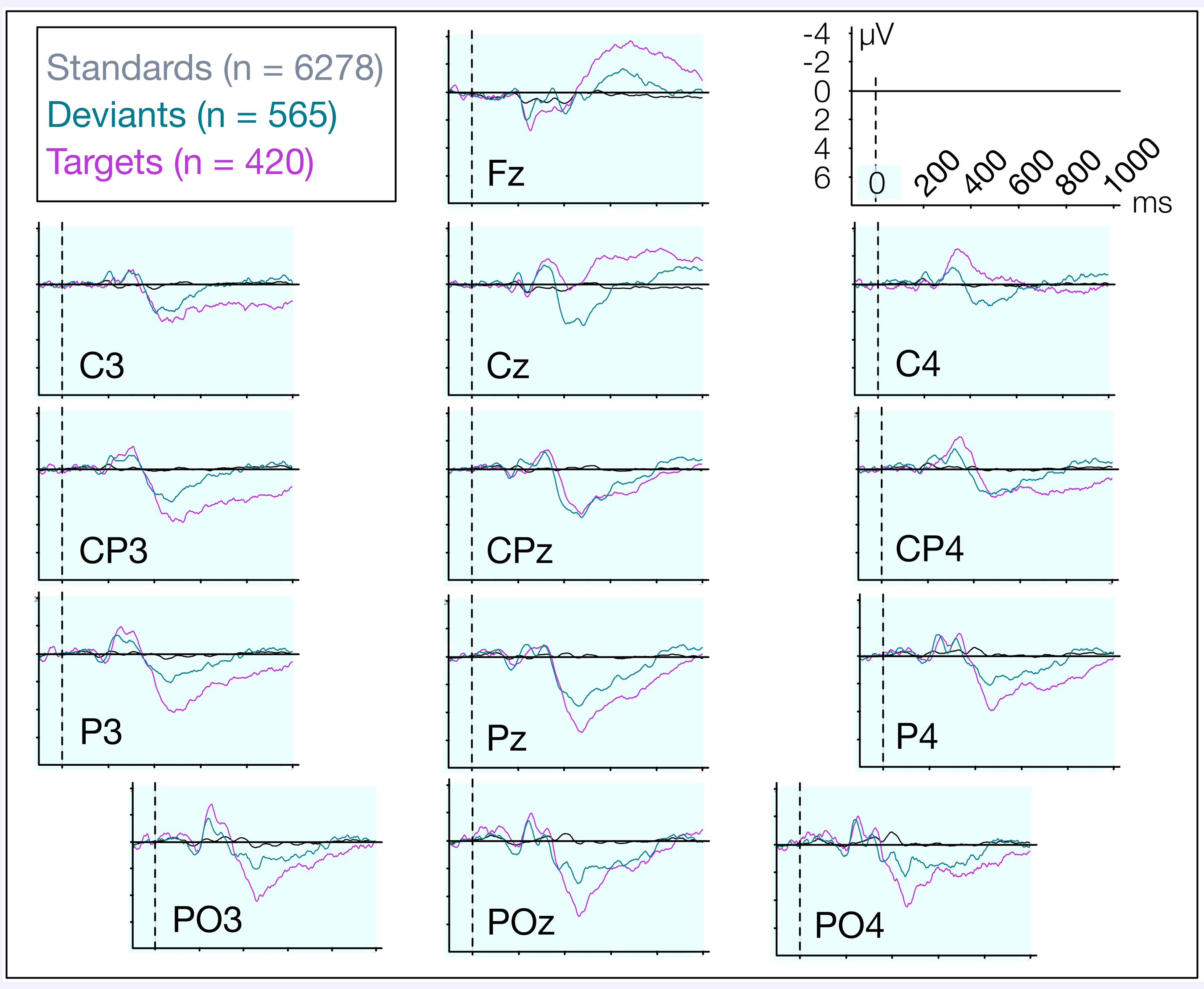
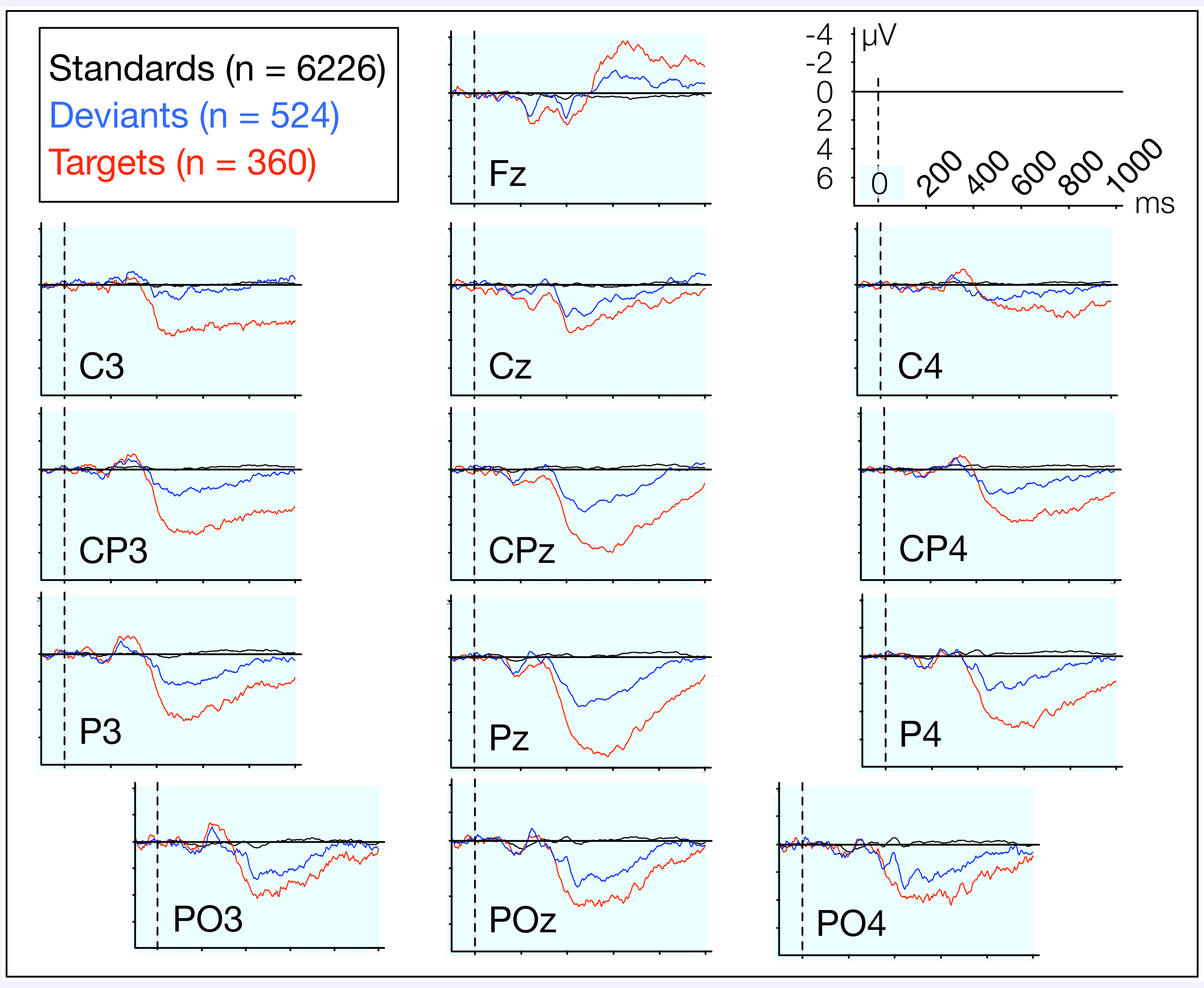


Figure 2: ERP Activity at Electrode Pz: Broad sustained ERP activity on deviant and target stimuli under both conditions at electrode Pz starting at 350 ms. We found a bigger late positivity effect on targets for the late window in the labyrinth oddball condition compared to the oddball condition. The late positivity effect on deviants was reduced in amplitude for the late window under the labyrinth oddball condition.

ERP Activity under Oddball Condition



ERP Activity under Labyrinth Oddball Condition



Discussion and Conclusions

Deviant and target stimuli could be shown to evoke positive parietal ERP activity under both oddball conditions. Complex behavior during HMI (labyrinth oddball condition) elicits a broader parietal positivity on target stimuli with higher amplitude in the early and late window. The stronger positivity effect in the early window at electrode Pz for target compared to non-target deviant stimuli is probably caused by differences in P300 expression due to different behavioral relevance of the stimuli [6, 8]. On the other hand, differences in the late positivity effect on target versus deviant stimuli in the late window that were only observable under labyrinth oddball condition are likely to be caused by the parietal prospective positivity, elicited by configuration of PM tasks as shown in [1, 9].

The significant difference of the later part of the parietal positive ERP complex might be detectable by a classifier. When applying Brain Reading [5] or passive BCIs [10], this detectable difference could, for example, be used to change the support of a human interacting with a machine regarding the requirements of the PM task. Hence, results found in this study are highly relevant for the improvement of the passive support of HMI, as already shown for the prediction of successful recognition of task-relevant stimuli [5, 3].

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