Studying the effectiveness of immersion for neurofeedback in mixed/virtual reality

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We describe a methodology for the assessment of the efficiency of virtual or mixed reality spaces as neurofeedback (NF) training applications [1]. We hypothesize that virtual environments induce high spatial presence that can serve as an effective reward for NF training. To test this hypothesis, for NF training we are using an audio-visual virtual environment in a mixed reality system called the eXperience Induction Machine (XIM) and its desktop version as a low immersion control. A number of subjective, attention performance and brain activity related tests are used in combination to assess the possible changes caused by NF training between two participant groups.

Methods

Each participant from the low or /high immersion groups (N=7 each) is exposed to 8-10 training sessions of approx 40 min duration (21 min overall training time, 6-7 trials of 3 min). The self-motion reward was contingent on meeting the combined power threshold in three EEG frequency bands: SMR (12-15Hz), and inhibits theta (4-11) and beta (19-30). Training protocol and signal processing were same as in [3].

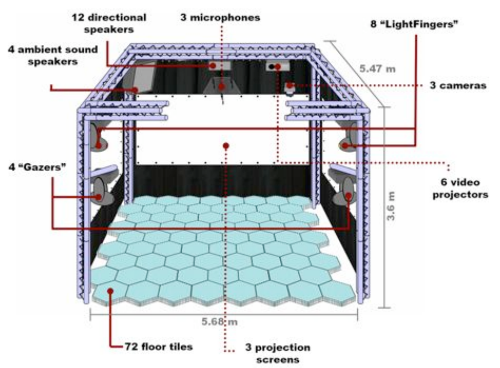

Figure 1: Technical infrastructure of the eXperience Induction Machine indicating the main components [2]. The space covers an area of 5.5x5.5m, and is equipped with the following devices: 3 cameras at the top of the rig provide a "bird's eye view", 3 microphones in the center, 8 steerable theater lights ("LightFingers"), 4 steerable color cameras ("Gazers"), 16 speakers with the corresponding sound equipment. The space is surrounded by 3 projection screens (2.25m x 5m), 6 video projectors are used for displaying content. The floor of the space consists of 72 custom built tiles, each of which can measure weight, and has a build in color light source.

Figure 2: Neurofeedback participant navigating in the virtual forest over predetermined path.

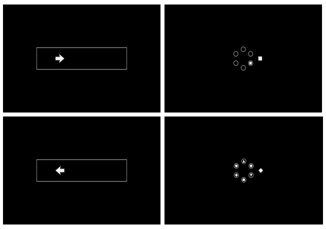

Figure 3: Examples of non-verbal Stroop task (congruent and incongruent arrow conditions) and Flanker task (low and high load conditions).

Before and after the training we used **a number of measures**:
- quantitative 19-channel EEG (qEEG) for 2 relaxation conditions (eyes closed, eyes open) and 1 training trial;
- Visual Continuous Performance Task (VCPT) – GO/NOGO task;
- learning curves for entraining of SMR band power;
- attention performance (Flanker and non-verbal Stroop tasks);
- subjective experience ratings (Flow Scales Questionnaire, [4]).

Interim conclusions

We have validated a system where NF reward is provided by navigation through virtual reality. This can be seen as another type of BCI system enhancing traditional approaches based on motor imagery [5]. The effectiveness of the system can be objectively assessed using qEEG and performance in attention tasks. Combined with subjective measures (e.g. Flow scales), the system might be fine-tuned to allow personalized NF training solutions.

XIM group results

High immersion group have currently finished the training and a number of enhancements can be seen across different measures.

qEEG Comparing pre-training open eyes condition and post-training brain maps showed a significant increase in SMR band power for the areas F4 and F8. Performance during VCPT also showed significant changes in the area of C4 (Figure 4).

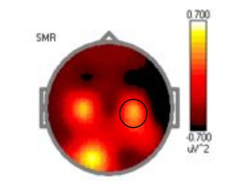

Figure 4: SMR power, grand mean between pre- and post-recordings while performing VSPT task. .

Attention Performance marginally improved for the Stroop task (decreased error rate for incongruent conditions, 8% vs. 2%) but not for the Flanker task. For GO/NOGO task, reactions times were significantly decreased: 483.3±9.8 for pre-training vs. 425.3±8.5 ms for post-training ($p<0.05$).

Subjective experience Two scales from the flow questionnaire showed to be most salient: Merging of Action and Awareness, and Transformation of Time.

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