

# A user-focused study of auditory P300 brain-computer interface design

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**Introduction:** Attention-mediated neural signals such as the P300 response allow some paralyzed patients to communicate via a speller device. New auditory speller devices that aid a listener's ability to selectively listen may increase the bit rate of communication. However, basic psychophysical studies probing stimulus design and ergonomic issues are lacking. Furthermore, there are untested usability concerns related to learning and memory load of new fixed-order and alphabetic-based auditory P300 BCI design, such as the new *charStreamer* paradigm [1].

**Methods:** Trials were divided into three conditions: alphabetic, fixed-order (non-alphabetic), and random (changing order). The alphabetic condition closely matches the *charStreamer* paradigm proposed in [1]: tokens (letters plus several additional commands) were parsed into three spatial locations in alphabetic order (left to right). In the fixed-order condition, tokens with similar pronunciations (like letters 'b', 'c', 'e') were separated. The random condition also began with this same separation of similar letters; however, the ordering was pseudo-randomly shuffled, such that subjects could not predict when the target token would occur. In order to investigate learning effects, data was analyzed at the initial (first 9 trials) and final (last 9 trials) stage of the experiment (27 trials in total). **Behavioral:** To test each subject's ability to detect target tokens in each condition, subjects were asked whether the target occurred once or twice. **Physiological:** Pupillometry is a corollary of the attention-based effort and brain activation in a task [2]. Pupillometry was measured using EyeLink1000 eye tracker. **Subjective:** To assess the subject's experience of cognitive load, the NASA Task Load Index (TLX; [3]) survey was completed after the experiment.

**Results:** **Behavioral:** There were no significant differences between the accuracies of any condition in the initial trials or the final trials ( $p > 0.12$ , all) or between any one condition's accuracy from initial to the final trials ( $p > 0.3$ , all). **Physiological:** Mean pupil size in the fixed-order condition was significantly greater than alphabetic and random in early trials ( $p = 0.04$ ,  $p = 0.02$  respectively; uncorrected, Fig. 1a). Within the fixed-order trials, mean pupil size decreased from the initial trials to the final trials ( $p = 0.03$ ). **Subjective:** Subjects rated the random condition significantly harder than both the fixed-order and alphabetic condition ( $p = 0.04$ ,  $p = 0.0005$  respectively; uncorrected, Fig. 1b). The greater difficulty of fixed-order vs. alphabetic was not significant ( $p = 0.07$ ).

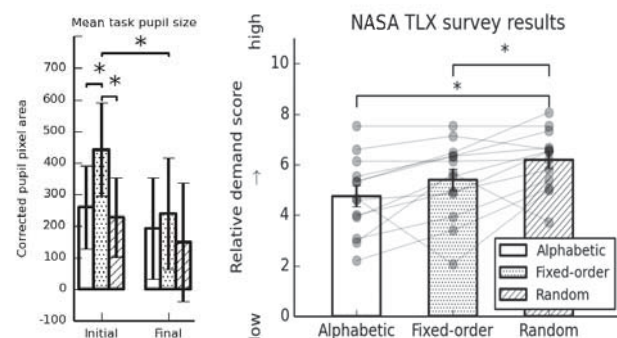
**Discussion:** **Behavioral:** Accuracy in discriminating the target was the only measure used that relates each condition to a projected bit rate, thus these findings mainly provide an opportunity to compare usability issues. **Physiological:** The fixed-order condition elicits the highest relative pupil size ( $p = 0.03$ ), which is likely due to the relatively high cognitive load involved in memorizing the fixed-ordering—an activity that would not have been necessary in alphabetic-order or feasible in random-order trials. The significant decrease in pupil size for only the fixed-order condition from the initial to final trials (Fig. 1b) suggests that subjects learned and used the fixed-ordering over the course of the experiment. **Subjective:** Subjects rated the fixed-order condition as easier than the random-order condition, which also suggests that they were able to learn the fixed ordering as an informative cue to reduce task difficulty. From these findings we conclude that, with exposure, a paradigm with an arbitrary, but fixed-order presentation, may approach the same usability as a known (i.e., alphabetic) order, whereas an unpredictable pattern may always impact usability. Therefore, alphabetic-ordering or alternative fixed-orderings may increase the usability of speller systems.

**Significance:** These findings suggest that leveraging both subjective and objective measures of user effort can lead to further optimizations of BCI speller paradigms.

## References:

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**Figure 1.** Bars indicate the subject mean ( $\pm$  SEM) *a*) **Physiological (left):** Mean pupil size (baseline corrected) for each condition for the first 9 trials (initial) vs. the last 9 trials (final). *b*) **Subjective (right):** Reported weighted difficulty according to the NASA TLX survey.