Cognitive Perception of Unfamiliar Electro-cutaneous Grip Force Response by an ERP P300 Component Analysis

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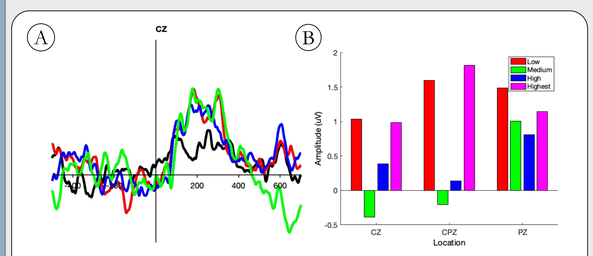
Abstract

Transcutaneous electrical nerve stimulation (TENS) has been employed to elicit graded grip force response, yet researchers showed that subjects often reported difficulty generating more than 3 force levels. Our hypothesis was that event related potential (ERP) would reflect different levels of stimuli when force level responses could not. We recruited six intact limb individuals for this study. After a brief training phase, subjects produced graded grip force response using a dynamometer based on TENS at threshold and two higher pulse widths which represented three stimulation intensities. We recorded electroencephalogram (EEG) during the main experiment consisting of three blocks of grip force trials. The experiment demonstrated that for subjects who were not trained on the highest stimulation and couldn't generate statistically largest force, ERP was not applicable for identifying the highest stimulus. However, EEG classification results hinted at potential discrimination patterns among stimulation levels. The result suggested limited efficacy of the employment of ERP components to probe cognitive processing of sensory feedback based on TENS.

Background



- P300 is claimed to represent the attention resource brain allocates for stimulation.
- Preliminary experiment demonstrated 1) distinction of P300 amplitude response for high and highest stimulations for 2 subjects and 2) observed U shape in the plot. This paper would expand on previous experiment.

Fig.1 (A) Sample P300 waveform based on CZ channel with 4 different stimulation levels. (B)Preliminary experiment (2 subjects) with U-shape observation.

Experiment Methods

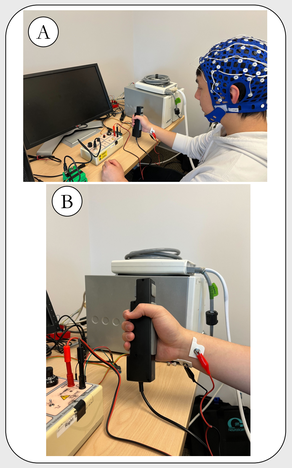


Fig.2 (A) (B) Subject holding the dynamometer, with TENS applied to sensitive positions.

- Sensory mapping & threshold detection
- Three-block design

Block 1: subjects gripped the dynamometer according to the same three levels of TENS in training phase.
Block 2: passive stimulations with no force response required, using the previous three intensity levels.
Block 3: the same three stimulation levels secretly applied with a highest pulse width.

- Monte Carlo Simulation

Ran Monte Carlo simulations for both force response and reaction time of each stimulation level on blocks 1 and 3 for each subject.

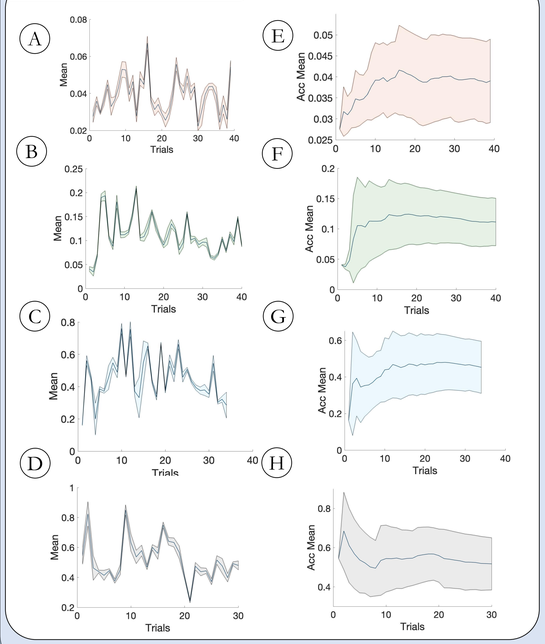
- EEG classification
- Learning trend verification

Table 1 Experiment three-block design.

	Block 1	Block 2	Block 3
Stimulation Types	Low, Medium, High	Low, Medium, High, Subthreshold	Low, Medium, High, Highest
Response Required	Yes	No	Yes

Learning Trend Verification

Force Response



Interested to see if subjects were biased by habituation or started learning the stimulations.

Conducted several statistical analyses, including mean with std, accumulated mean, windowed mean, difference/ratio between contiguous trials in force and reaction time for all subjects in block 1 and 3

Fig.7 Mean (left column) and accumulated mean (right column) for subject 2 (all six subjects show similar curves), block 3. 4 rows correspond to stimulation levels; Error bands represent std.

Experiment Results

Force Response

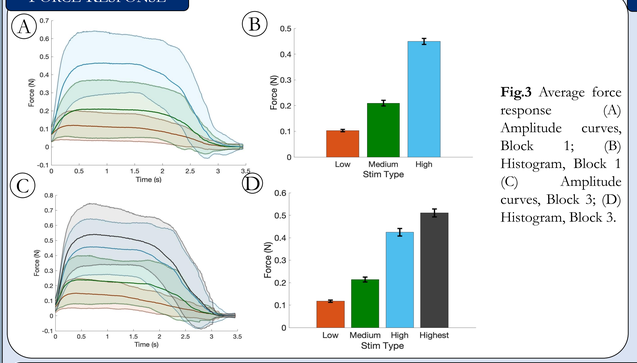


Fig.3 Average force response (A) Amplitude curves, Block 1; (B) Histogram, Block 1 (C) Amplitude curves, Block 3; (D) Histogram, Block 3.

Reaction Time

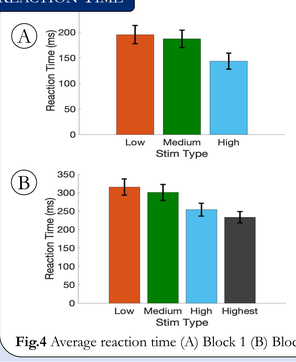
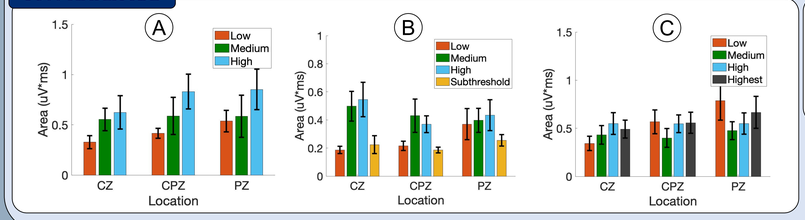


Fig.4 Average reaction time (A) Block 1 (B) Block 3.

Kruskal Wallis tests with post-hoc analysis were performed to compare force levels, reaction times, and P300 positive areas based on stimulation intensities within each block. In block 3 stimulation intensity was shown to impact force response (average $p < 1.45e\text{-}17$) and reaction time ($p < 5.37e\text{-}04$), but the force level difference between high and highest level was not statistically significant from post-hoc analysis ($p > 0.3$).

P300 Amplitude

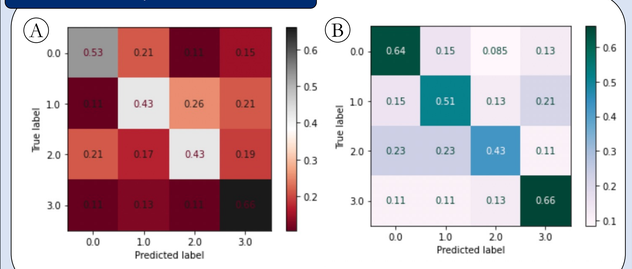


- High and highest stimulation levels are not distinguished
- U shape effect is not notable.

Fig.5 P300 numerical integration 250 – 500 ms (A) Block 1 (B) Block 2 (C) Block 3.

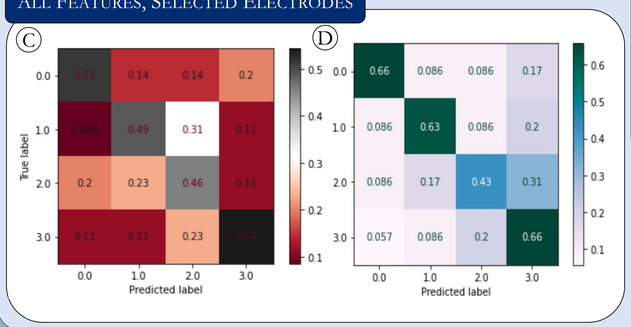
EEG Classification

All Features, All Electrodes



Apart from P300 numerical integration, we also looked at other 9 features from EEG: peak latency, peak amplitude, etc.; Classified EEG data using all 10 features by KNN, Naïve Bayes, LDA, QDA, Decision tree, Random forest, Logistic regression for all three blocks; Presented here are KNN and Random forest models for block 3.

All Features, Selected Electrodes



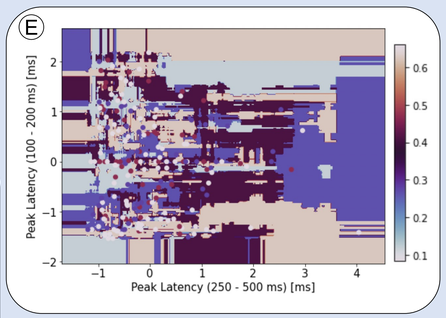


Fig.6 EEG Classification Heatmap results for block 3. Two classification algorithms are displayed here: (A)(C) for KNN and (B)(D) for Random forest. Also tried reducing the number of electrodes employed for training; (E) Classification with random forest of EEG data (represented by dots), using first two most significant features by decision tree. Color bar stands for classification accuracy.

Significance

- No statistical difference between P300 amplitude for high and highest stimulations.
- EEG classification exhibited limited success in pattern recognition.
- There's no learning trend observed.
- The "U shape" distribution of P300 amplitude as intensity level increased for both CPZ and PZ electrodes was not as obvious as in the preliminary experiment.

References

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Acknowledgment

This work is supported in part by the U.S. Department of Energy, Office of Science, Office of Advanced Scientific Computing Research under award number DE-SC0022150.