Electrophysiological Patterns of Skilled Motor Movements

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Introduction

- Skilled movements are characterized by decreased cortical activation in the motor cortex and decreased coherence between neuronal populations (Deeney et al., 2010; Hauffler et al. 2000)
  - Over-training of a skilled activity can lead to the formation of focal task specific dystonia (FTSD)
  - FTSD is a movement disorder characterized by abnormal muscle contractions and the degradation of motor pathways in highly skilled individuals (musicians, athletes) (Herrojo Ruiz et al., 2008)
  - FTSD symptoms emerge only when these patients are performing their well-learned movements (Herrojo Ruiz et al., 2008).
- Beta frequency desynchronization and synchronization have been characterized in both FTSD patients and experts in various activities (marksmen, cricket batsmen, etc.) (Herrojo Ruiz et al, 2008; Jin et al, 2011).
- We used electroencephalography (EEG) to measure fluctuations in oscillatory activity during different conditions of external stimuli to investigate whether similar beta frequency signatures and response patterns may be present in healthy people while performing similar ('skilled') movements.

Hypotheses

Behavioral Questions:

1) No difference in errors between skilled and unskilled trials (Herrojo Ruiz et al. 2008; Hummel et al. 2002).

2) Greater variability of response times during the skilled trials (Furuya 2015 & Herrojo Ruiz et al. 2008).

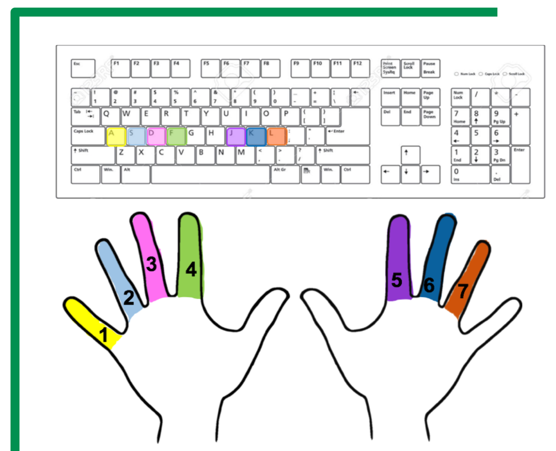
Electrophysiological Questions:

3) Reduced fluctuations in sensorimotor beta power (desynchronization and rebound) during 'skilled' compared to 'unskilled' movements. (Herrojo Ruiz et al. 2008; Jin et al., 2001).

4) Four separate sensorimotor beta (13-30 Hz) power decreases and rebounds within a trial for each character stimuli of the sequence. (Jurkewicz et al. 2006).

5) Reduced fluctuations in sensorimotor beta power over all trial types for people with a higher skilled level compared to those with a lower skill level. (Hauffler et al. 2000; Deeney et al., 2010).

Methods



Data Collection:

Data was collected from 13 participants (9 f) aged 18-24 (mean age 20.3). Two trial types were tested: 'skilled' and 'unskilled' trials. 'Skilled' trial version: four characters appeared on the screen. There were seven potential characters the task could display: 'a', 's', 'd', 'f', 'j', 'k', or 'l'. Participants responded to the 'f' character stimulus with their left index finger (L2), the 'd' character stimulus with their left middle finger (L3), and so on until their right ring finger (R4). Thumbs (L1 & R1) and right pinky (R5) were not used (see image above). Unskilled' trial version: Four numbers (only 1-7) appeared on the screen. 'Participants fingers were numbered from left to right and excludes the thumbs (L1 & R1) and right pinky finger (R5). The same keys participants used to respond to the skilled version of the trial were used in the unskilled version. The number '1' asked the participant to respond with the 'a' key using their left pinky finger. (L5).

Participants performed 480 trials over 12 blocks (40 trials per block, 240 total skilled trials) in a randomized (both trial types in one block) and fixed (one trial type per block) order. All participants performed a typing assessment prior to starting the experiment.

EEG data was collected using a 64-channel Active Two system sampled at 1024 Hz.

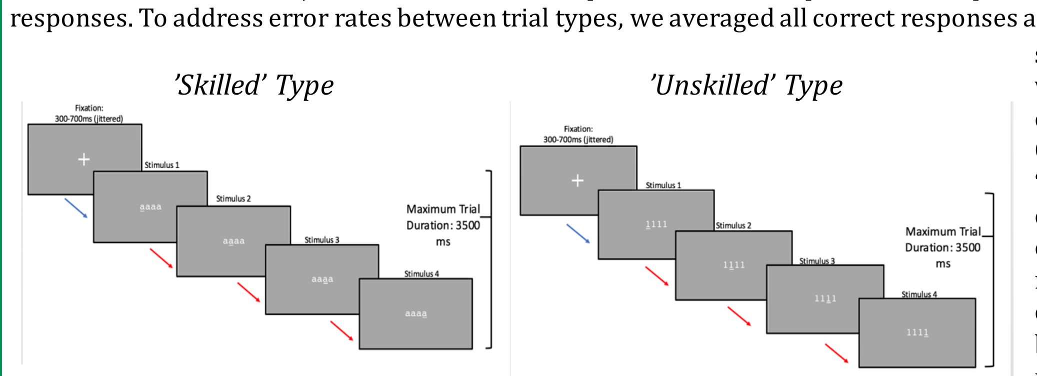
Data Analysis:

Data preprocessing was performed using MATLAB 2017b and eeglab functions (A Delorme & S Makeig, 2004). Each dataset was re-referenced to average, underwent a 0.5 Hz low-pass filter and ICA . Components were manually inspected and blinking artifacts removed. Automatic rejections were implemented in eeglab to remove additional artifacts.

Spectrograms were generated using MATLAB 2017b and eeglab functions. Per epoch, the power spectral density was calculated using a Hilbert transformation, then the amplitude extracted, baseline subtracted and divided by the SD . Averaged log(power) from 13-30Hz per condition used for statistical comparisons. Spectrograms were aligned either to the first stimulus onset and first keypress to investigate beta desynchronization and aligned to second, third, or fourth key presses when investigating beta dynamics for responses 2-4 and beta rebound. Threshold values were set to $t = 2.718$ to indicate differences with an uncorrected significance. No differences survived correction for multiple comparisons.

To address time variability, we averaged the first reaction times and the second, third, and fourth reaction times across all trials for all subjects. We excluded '0' response times and separate first response from consecutive responses. To address error rates between trial types, we averaged all correct responses across all trials for each subject. Non-responses were included in the error calculations.

Classes of 'proficient' and 'novice' typists were created based on calculating character per minute scores and classified as above or below the mean score respectively.



Blue arrows indicate automatic advancement after jittered time period (average of 500ms). Red arrows indicates screen advance only with a key press.

Response Error and Variability

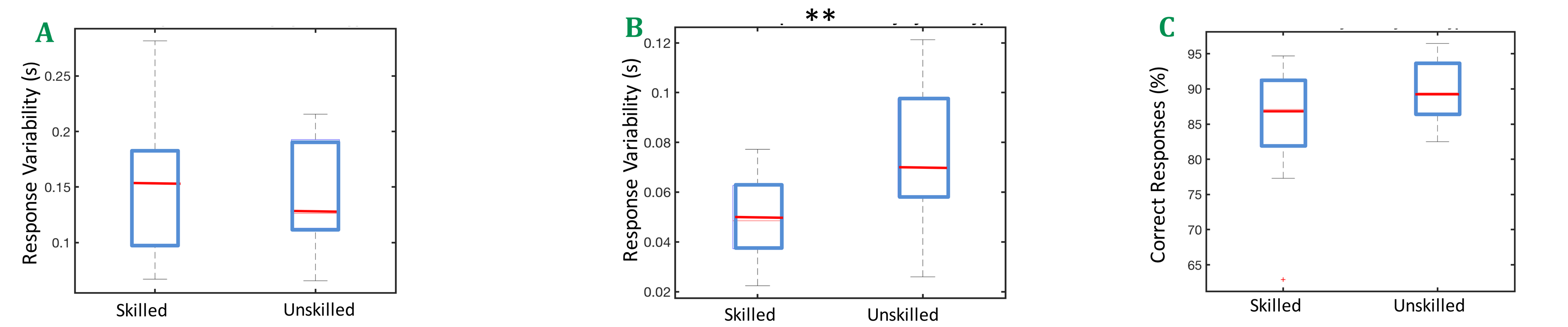


Figure 1: (A) Box and whisker plot of response time variability for first keypresses in skilled and unskilled trial types averaged across subjects (p=.0194). Center red line indicates median, box edges are 25th and 75th percentile, whiskers extend to most extreme data points, and red crosses represent outliers (more than three standard deviations from the mean). (B) Box and whisker plot of response time variability for second, third, and fourth key presses for skilled and unskilled trial types (p= .0086). (C) Percent errors for skilled and unskilled trial types averaged across all subjects (p=.081). Error calculations included non-responses while response time variability did not. ** indicates significance difference between trial types.

Spectrogram Plots

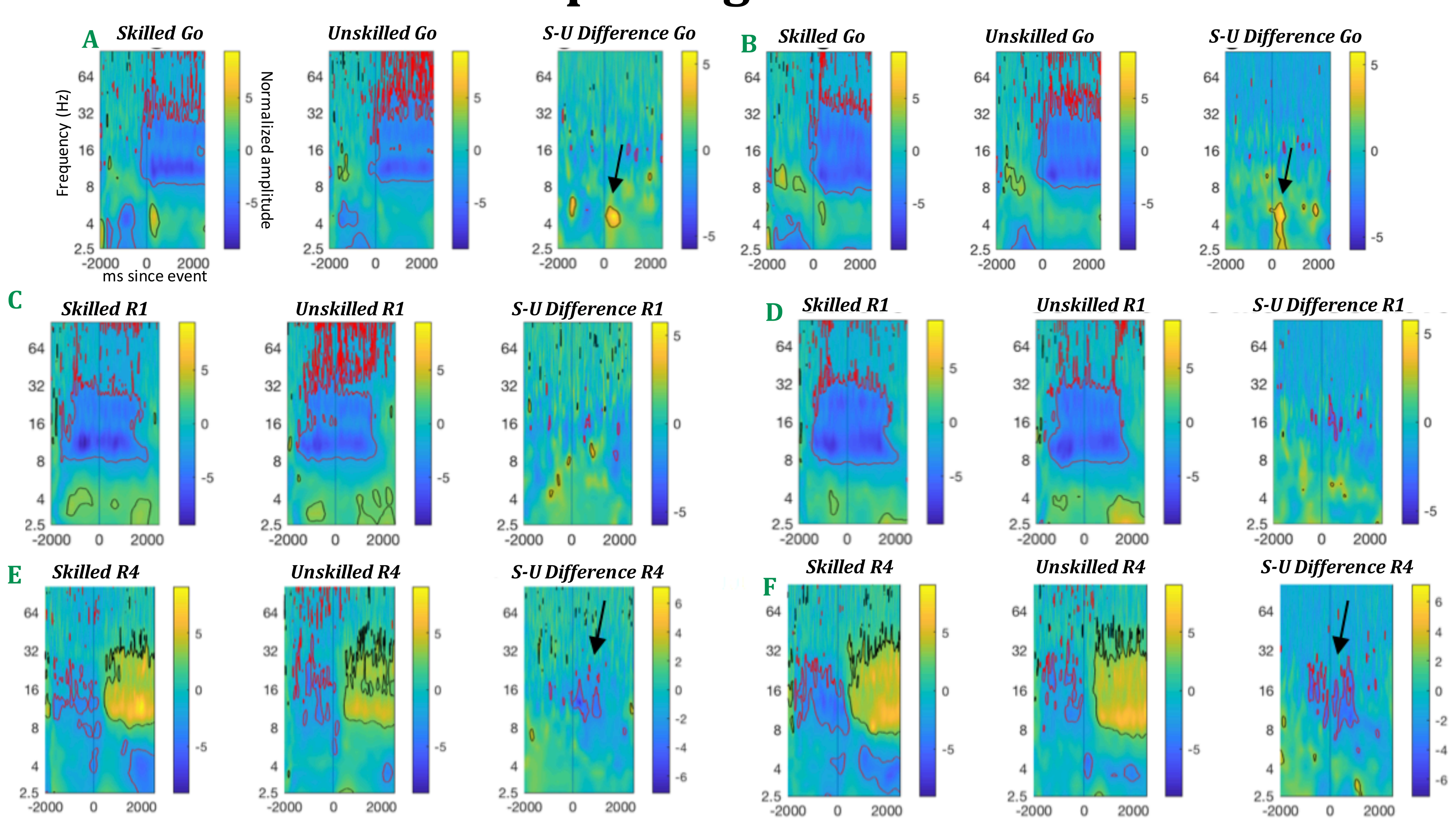


Figure 2: (A)-(F) Spectrogram plots of power spectral density See (A) for axes labels. Uncorrected statistically significant areas outlined in red and black with a threshold of p = .01. S plots indicate skilled trial data, U plots indicate unskilled trial data, and S-U plots indicate trial differences. (A) Set to the trial start "Go" cue for C3 electrode channel. (B) Set to the trial start "Go" cue for the C4 electrode channel. Black arrow indicates theta increase observed in skilled trials after go cue. (C), (D) Set to the first recorded key press for electrodes C3 and C4 respectively (E), (F) Set to the fourth recorded key press for electrodes C3, C4 respectively. . Black arrow indicates weaker beta rebound observed in skilled trials after the fourth keypress. Implementing corrected statistics is a future direction for this study.

Typing Proficiency & Beta Power

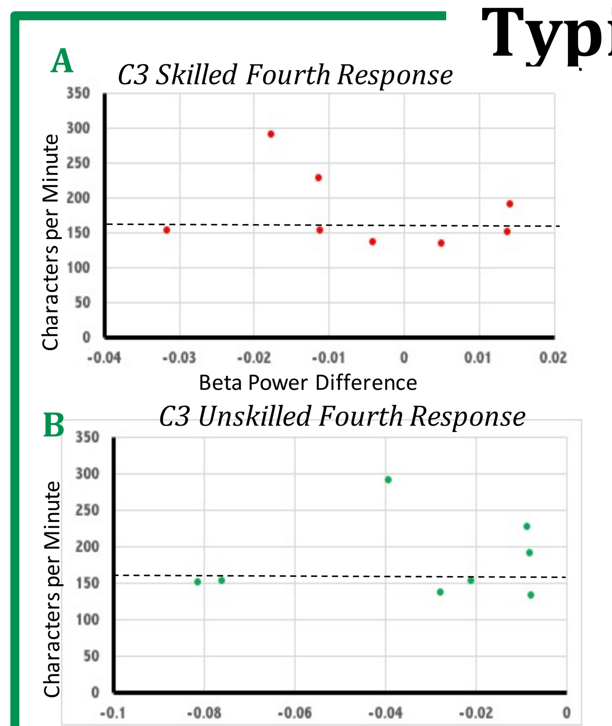
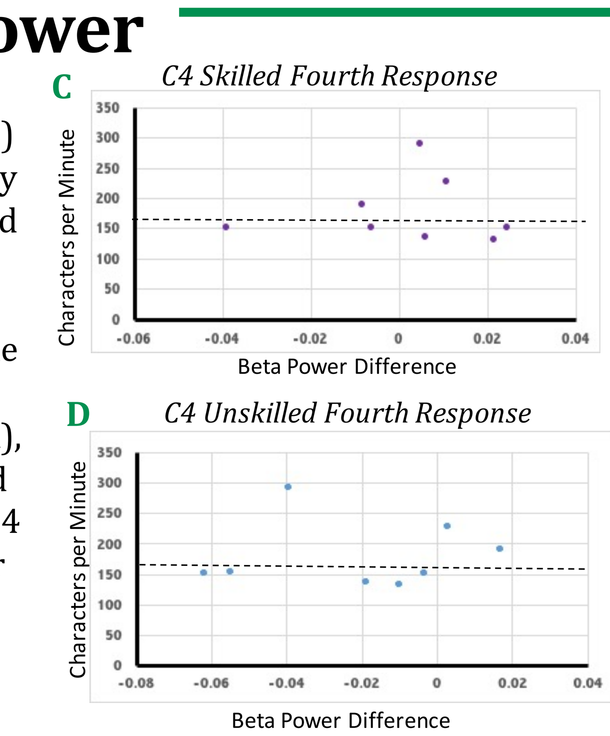


Figure 3: (A)-(D) Scatter plots of typing assessment data in characters per minute (y-axis) and post-movement beta increase after fourth key press/non-movement log(power) (x-axis). Dashed blue line indicates the typing assessment score that qualified participants as 'novice' or 'proficient' (y = 155). Scores above the dashed line considered proficient typists based on our assessment. R^2 values displayed in each graph. (A), (B) Beta power difference in skilled rebound and non-movement in channels C3 ($p= .5089$, $r^2=-.2756$), C4 ($p= .7581$, $r^2= .1305$) respectively. (C), (D) Beta power differences in unskilled rebound and non-movement in channels C3 ($p=.9473$, $r^2=.0281$), C4 ($p=.9201$, $r^2=.0526$) respectively.



Conclusions

Behavioral Questions:

1)Response Error: No significant difference in error rates between trial types, which is consistent with dystonic literature.

2) Response Variability: Variability in the first key press times showed no significant difference. However, variability between second, third, and fourth responses were significantly greater during the 'unskilled' trial types. This was unexpected because previous work has shown greater variability in FTSD patients (Herrojo Ruiz et al., 2008). However, these results do confer with data from previous skill-associated behavioral results

Electrophysiological Questions:

3) Beta Desynchronization & Rebound: No remarkable difference in beta desynchronization between trial types. We saw decreased beta power likely driven by a weaker beta rebound after the fourth key press in 'skilled' trials. This decrease in 'skilled' beta power is consistent with EEG signatures observed in patients with FSTD (Herrojo Ruiz et al., 2008). We observed an unexpected increase in theta band frequency activity during the 'skilled' trial types following the trial onset cue. This may be the product of a variation of 'conflict detection'. This occurs when interference of irrelevant stimuli affect a participant's reaction time and cortical processing to the relevant stimulus (APA, 2020). In the future, we will implement a cluster based correction to analyze the significance of the data.

4) Quantifying Beta Power Decreases: Our results more closely resembled a continuous reduction in beta power throughout the trial following the initial desynchronization. This decrease was consistent for both C3 and C4 electrodes as well as trial types. May infer that participants did not did not conceptualize each stimulus individually, but rather observed the string of stimuli prior to making their first response, and perhaps programmed the four button presses as a single motor command.

5)Correlation in Skill Level & Beta Power : No significant differences were observed in skilled or unskilled beta power values and typing ability in the C3 or C4 electrode. Similar results have been reported in skilled literature (Vogt et al., 2017)

The findings of this paper may have implications for both skill-associated research and focal task dystonia research. Prior skilled-movement literature has mainly assessed the conditions of skilled and unskilled in separate subjects. This study takes on a new approach of emulating these conditions in a single subject and observing how the conditions change their behavioral patterns and sensorimotor beta activity. More importantly, this study's results could have clinical implications because of its connection to the FTSD movement disorder. Identifying dystonic signatures in healthy people could assist in the creation of an early diagnosis test for at-risk FTSD groups.

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