The Effect of Stimulus Speed on the Bereitschaftspotential

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Introduction

Human actions are subconsciously planned well in advance before the initiation of movement itself. Even before you consciously decide to grab an object, like a glass of water or a set of car keys, your neural subconscious has already started planning your movement. The study of the neural processes involved in initiating and performing movement is integral to developing a better understanding of planned movement. This rising potential of brain activity is illustrated by the Bereitschaftspotential (BP) (Patil & Kochhar, 2016). The initiation of movement seen in the BP can aid in comprehending the mechanisms by which motor disabilities affect movement, which can lead to new progressive studies to prevent said disabilities. For example, Jahanshahi and Hallett (2003), have shown that amplitude, slope, and/or latency of BP can be impaired in people with motor disabilities. For these reasons, it is important to study the BP and its relevance to the connection of motor activities. Our experiment will attempt to answer how the speed of a visuomotor task affects the latency of the BP.

The planning phase of a motor task is essential to perform coordinated movements. Makoshi, Krolizak and Donkelaar (2011), studied this, as well as the supplementary motor area's (SMA) contribution to motor planning. Ten middle aged participants were outfitted with transcranial magnetic stimulation to probe the contribution of SMA to motor planning during a predictive load bearing task, which consisted of a participant, when cued, releasing a platform supporting their hand, which held a 2-kg mass. As predicted, the SMA contributed to the prediction of the sensory consequences of movement well before movement onset. It was also concluded that the BP could occur as early as one second prior to the movement onset.

The brain regions active during the motor planning were also researched by Grosse (2004). In his study the brain was examined while it prepared to respond to stimuli under a given number of time constraints. Electroencephalography (EEG) was used to study BP during a manifestation of cortical contribution to the pre-motor planning of voluntary movement. It was found that the BP was active in the motor cortex and SMA of the brain leading up to voluntary muscle movement.

Research efforts exploring various effects on the BP has been a highly debated topic throughout the last five decades. The literature has shown that the speed of a movement changes the duration of the BP (Patil & Kochhar, 2016). The speed of a movement in this context refers to the amount of time the performer has to acknowledge movement instruction, plan the movement, and finally, to execute the movement. For example, if the visuomotor stimulus is slow, the participant will have more time to prepare their actions, and therefore lead to a lengthened BP (Patil & Kochhar, 2016). Contrarily, if the stimulus is fast, the performer will have little preparation time, resulting in a shortened BP (Patil & Kochhar, 2016). The BP illustrates the computation in the brain during the time of understanding the required movement, the planning of that particular movement, and the actual performance of that motion.

Taylor (1978) designed a study that investigated the BP and its cortical distribution during the acquisition of a skilled serial motor response. Participants performed a single finger visuomotor task, in which they pressed one of six labeled buttons (numbered 1-6, not in sequential order) as fast as possible when prompted; this task was the standard condition. The experimental condition involved the participants pressing the six buttons in a random pattern (e.g. 1-6-3-5-4-2) with no repetitions of any number. Results showed that the magnitude of the BP increased steadily over the trials in which the response time was decreasing; furthermore, significant response time, electrode and trial main effects, and electrode by trial interactions were found (Taylor, 1978). This means that the participants showed that they were more prepared to respond to the condition (BP magnitude increased), and thus were able to perform the task faster and more effectively.

Further research done by Benecke, Dick, Rothwell, Day, & Marsden examined nine healthy participants performing four motor tasks of varying speed and those corresponding BP were recorded. The tasks included elbow flexion, finger flexion, flexion and squeezing simultaneously, and a sequential flex and then squeeze (Benecke et al., 1985). They found that when told to perform the tasks with little time before performance, the amount of time the BP occurred over was shortened. This suggests that when subjects are given less time to plan actions, the latency of their BP will be lessened. The contrary is also true, we see that when more time is given to plan and react, the BP latency increases. In an additional study, the latency and amplitude of BP were measured across 14 subjects. The participants were requested to repeat the same wrist flexion movement at a self-paced rate (once every five seconds). The findings show that the BP in these cases start earlier because of the extended amount of time provided to prepare the action (Shibasaki & Hallet, 2006).

In a study by Cui et al., (2000) the effect of a bimanual motor task on BP was measured by two tasks. One task consisted of pinching both thumbs to the second fingers, and the next task consisted of pinching the thumbs consecutively to the second, fifth and then returning to the second fingers. They found an increase in amplitude and earlier onset of the movement, as well as an increase in intensity and duration. As the movement became more intense, more planning was needed but less time was allowed, which related to the amplitude and onset of the BP. The amplitude of the BP was also an area of discussion in Freude, Ullsperger, Kriiger and Pietschmann’s (1988) study. Freude and colleagues examined how the speed of a cognitive motor task effected the BP. They had 14 healthy male subjects solve arithmetic tasks under an increasing time pressure and press one of the corresponding 3 keys. Interestingly, the increase in speed impacted the amplitude of the BP and not the latency. This is likely because the added mental task has different effects on motor preparation and BP.

In the current study, we observed how rapidity of stimuli alters the extent of the BP. In this study, participants responded to circles descending within different vertical columns on the screen. As the circles reached the target area at the bottom of each column, the subject pressed a key mapped to its respective target. By manipulating visibility time of the stimulus, we used EEG data to observe the effect of rate-change on BP results. Our hypothesis is that when speed of the activity is increased, the BP will have a shorter duration, with the early BP having a later onset before the movement (Shibasaki & Hallett, 2006). We expect that this would shorten both the early and late stages of the BP. Our experiment will attempt to answer the question: how does the speed of a visuomotor task affect the latency of the BP? Our focus is on how the quickness of a movement stimulus affects the latency of the measured BP. The latency describes the overall length of the BP, including the planning through movement execution phases. In our experiment, we will be using EEG (electroencephalography), and specifically the “Muse headband” to measure the BP.

Methods

Participants

In this experiment, there were 30 participants, 11 males and 19 females, four of which were left-handed. The mean age was 22, with a standard deviation of 2.0. All subjects had normal, or corrected-to-normal vision, with no known neurological impairments, and performed written informed consent prior to participation. None of the subjects had previous experience with this particular task. We followed the University of Victoria human research ethics to ensure all the participants were treated ethically.

Apparatus/task

Participants were seated during each session in a group of 16 and a group of 14 in front of Apple 21.5 inch (diagonal) LED backlit display computer monitors (1920x1080p), with MUSE headbands on, while MUSE electrodes relayed EEG to the monitor in front of them. The experiment took place in a quiet, fully lit room and was outfitted with standard computer desk chairs that could be adjusted to the correct height based on the participant. The tasks were coded in MATLAB programming environment (Version 8.6, Mathworks, Natick, U.S.A.) using the Psychophysics Toolbox extension (Brainard, 1997). During the task, participants watched blue and green colored dots cascade down the center of a black screen, guided along four white centered vertical lines which ran through the length of the top three quarters of the screen. They then disappeared after passing one horizontal line at the bottom. The colored dots were either circular, and approximately 1.5 cm in diameter, or elongated, with the same horizontal diameter as the smaller circles, but the vertical diameter was approximately four times larger at 6cm. These blue or green colored dots were visible on the monitor screen for 800 or 1200ms, depending on their initial starting position. Positioned in the center of the of the four vertical lines was a white cross (“+”) symbol that the participants were instructed to focus their gaze on during the entire experiment. Each student had a USB keyboard in front of them which was connected to the computer monitor. The task had four vertical lines along which the shapes descended on. Depending on which color the shape was presented in dictated which keys were to be pressed by which hand/finger. The second-fifth digits of the left hand were mapped to the keys r,e,w,q, respectively, and u,i,o,p for the second-fifth digits of the right hand, respectively.

Procedure

Before beginning the experiment, participants completed a fatigue questionnaire to determine their level of mental and physical tiredness before running the task. Each participant wore a MUSE EEG headband during the experiment. Once the headbands produced consistent EEG, the participant selected any key on the keyboard to begin the task. There were no practice trials prior to the experiment. Subjects positioned their hands/fingers so that they could hit the correct key while maintaining eye contact with the ("+") symbol in the center of the monitor. Blue and green colored shapes descended on the white vertical lines and disappeared after reaching the white horizontal line. Participants aimed to hit the key on the correct hand (blue designated for the right hand, green for the left), at the time that corresponded with the shape hitting the horizontal white line. If the correct key was hit at the correct time, the white cross simultaneously turned a cyan color and then returned to white before the next shape fell. If the incorrect key was hit, or if the timing was incorrect, the white cross quickly flashed a red color and then returned to white before another symbol fell. Each participant ran through the whole program, which lasted about 30 minutes, and contained four blocks of the task, consisting of multiple trials with different conditions including Complexity, which was a rapid succession of four circles along different lines. Speed, where the circles started half way down the screen. Accuracy, which was the switch between the precise circles and the imprecise. Dominant versus nondominant hand, which was the switch between hands depending on the color of the circle and magnitude, which was the simultaneous press of all four keys. Between each of the 4 blocks, participants would have to press the ‘a’ key to begin the next block. At the end of the fourth and final block, the screen would indicate that the experiment had ended, and the MATLAB program would quit/shut down automatically. The participants then removed, cleaned, and returned their MUSE headband to its correct storage placement. Subjects then filled out the same fatigue questionnaire that they completed before the task, indicating whether or not the experiment progressed their status of fatigue.

Data collection

EEG data in the MUSE group was recorded from a MUSE EEG headband with research preset AD (500Hz sampling rate, no onboard data processing: InteraXon, Ontario, Canada) (see http://developer.choosemuse.com/ hardware-firmware/hardware-specifications for full technical specifications). Using the muse-io SDK, we streamed data from the MUSE EEG system directly to MATLAB via the open sound control (OSC) protocol (see http://www.neuroeconlab.com/muse.html for all configuration, setup, and acquisition methods and software). Data retrieved from streaming data into MATLAB was recorded for two seconds prior to the target reaching the response bar and for 500 ms following.

Data analysis

Data was processed with Brain Vision Analyzer 2 software (Version 2.1.1, Brainproducts, GmbH,Munich,Germany), and was resampled to 250 Hz. The data was then filtered using a dual pass Butterworth filter with a pass band of 0.1 Hz to 15 Hz in addition to a 60 Hz notch filter. Segments encompassing the onset of each event of interest (2,000ms before to 500 ms after) were extracted, and a baseline correction from -2000 to -1800ms was applied.

Artifact rejection algorithm with gradient of 10 µV/ms and 100 µV absolute difference criteria was used. The TP9 and TP10 electrodes were pooled. The data was then re-segmented by condition. This was time-locked to when the target stimulus reached the response bar indicating that participants are here to respond. Data for each conditional waveform were averaged for each participant. To determine the amplitude of the early and late BP potential, the peak amplitude of each at time 0 ms and -500 ms was extracted for each condition and participant. To determine the onset of the early BP, we determined the time in which the waveform surpassed a voltage of -2 µV.

Results

The average of the 30 participant's BPs for full versus reduced time constraints is shown in figure 1. For the reduced time constraint, the BP wasn't apparent until 324ms before the movement onset. Besides this the BP followed a predictable pattern.

Results from our study demonstrated that the 'full' time (FT) group showed better accuracy and greater brain activity (BP EEG data) when compared to the 'reduced' time(RT) group. Specifically, data analysis collected from our accuracy sample (n=26) shows that FT accuracy (M = 0.500%, SD = 0.197) and 'reduced' time (RT) accuracy (M=0.392%, SD=0.256) shows statistical significance during an independent paired t-test (M_d = 0.108[0.048, 0.168], $t(25) = 3.72$, $p = 0.001$[a = 0.05], $d = -0.12$). This means when participants are given more time to react to the stimulus, they are more accurate.

Furthermore data analysis collected from the BP sample (n = 30) shows that the FT (M = -0.536uV, SD = 1.141) and the RT (M = -0.824uV, SD = 1.236) groups showed no statistical significance during an independent paired t-test (M_d = 0.288[-1.151, 0.614] $t(29) = 1.80$, p =

0.08[a = 0.05], *d* = 0.289). This means that, when looking at the t-test, there was no significance between groups for the amount of brain activity (shown in EEG; uV) and the time to react during the task (latency of the task); however, our Cohen's *d* reports that the FT group was 0.289 SD units above the RT group on average.

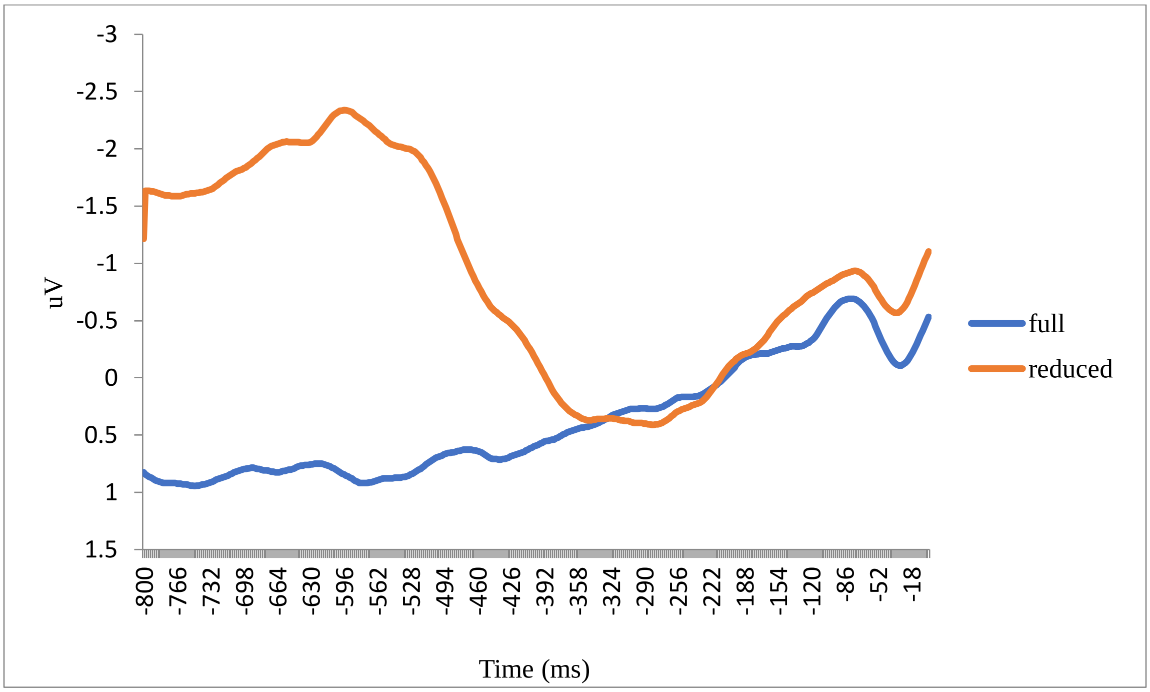

Figure 1. Grand average waveform of the full and reduced time tasks when looking at voltage over time.

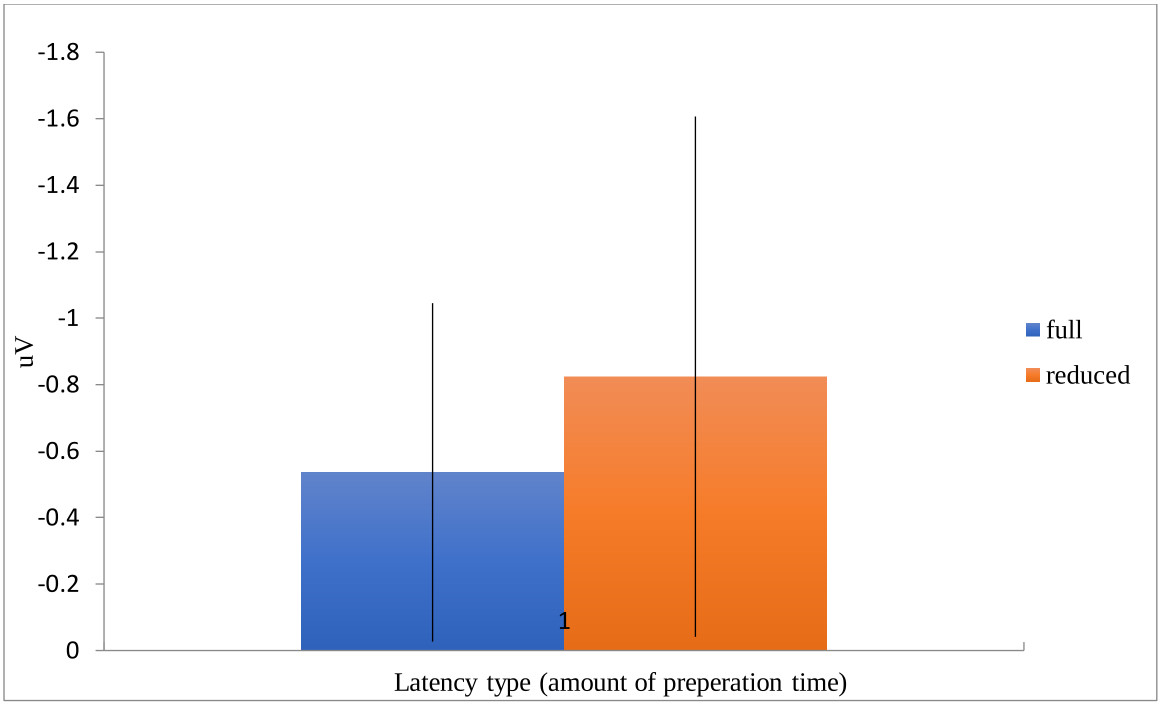

Figure 2. Average EEG data when looking at Bereitcschaftspotential between tasks - the amount of preparation time given to the participant (either full or reduced, i.e. less time). [Data with 95% confidence intervals].

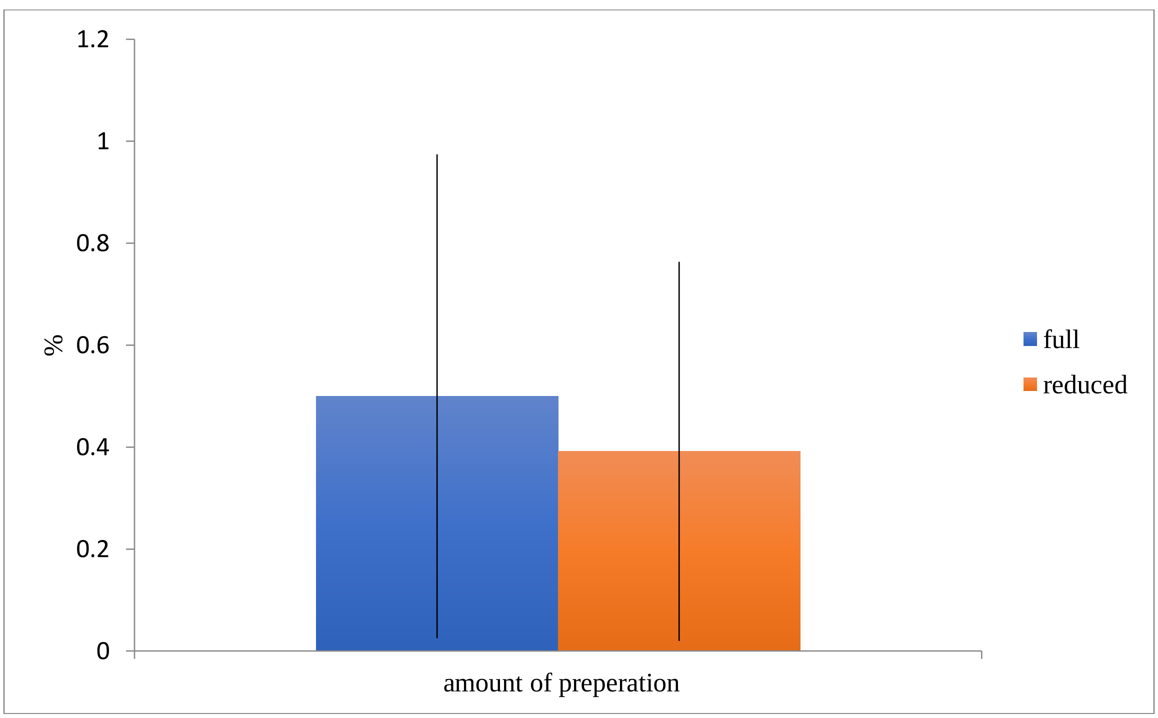

Figure 3. Average EEG data when looking at the accuracy between tasks - the amount of preparation time given to the participant (either full or reduced, i.e. less time). [Data with 95% confidence intervals].

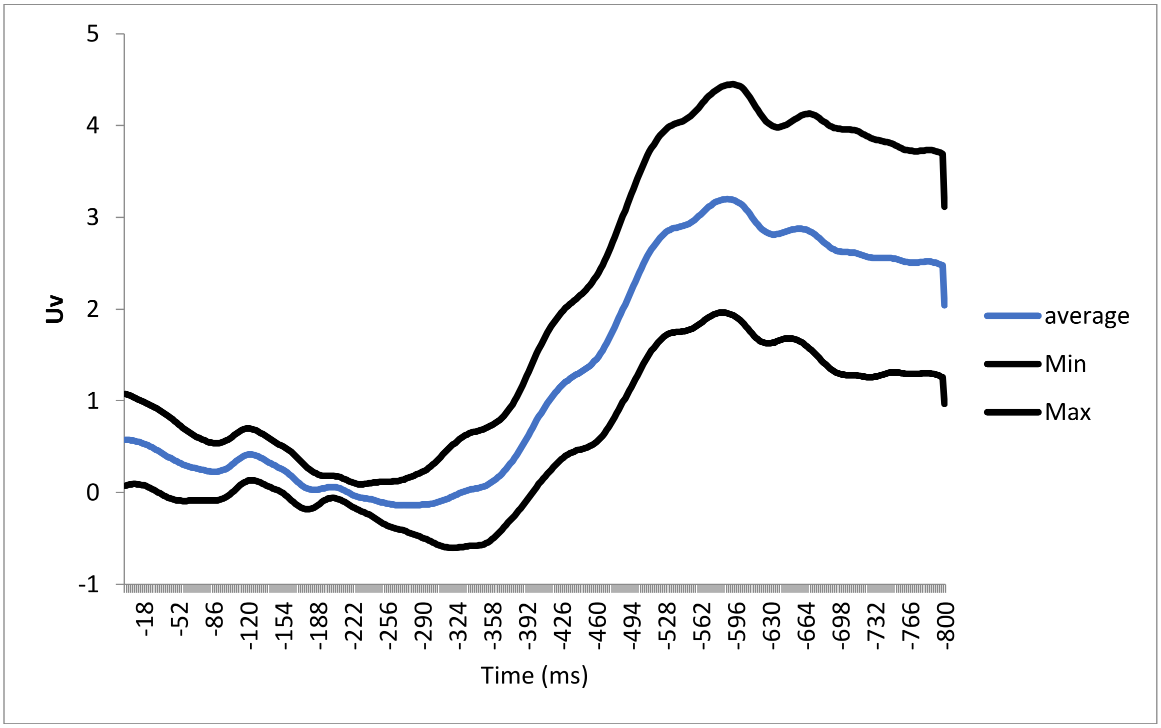

Figure 4. This graph shows mean difference (M_d) data between the FT and RT groups when looking at microvolts (uV) over time (ms) from our EEG data; area shows a confidence interval (CI) between the black lines (CImin/CImax).

Discussion

In the current study, we attempted to answer how the speed of a visuomotor task affects the BP. From our results, it is shown that the magnitude of the BP decreases when stimulus speed is increased. This result of BP dependence on stimulus speed is in line with our hypothesis which stated that when speed of the activity is increased, the BP will have a shorter duration, with the early BP having a later onset before the movement (Shibasaki & Hallett, 2006). We also expected similar BP amplitude, but that the illustration would start later with a quicker movement stimulus. We predicted that this would shorten both the early and late stages of the BP. Our findings suggest that the amplitude of the BP was larger with the increased speed of stimulus trials. Furthermore, the target accuracy was shown to significantly decrease during the faster condition. In the current study, we found that a decrease in the amount of time to plan and react to a moving stimulus has an effect on the BP, and therefore, by studying the BP will allow us to better understand the phases of movement planning, preparation, and execution.

Our results matched the findings of other studies (Patil & Kochhar, 2016; Benecke et al., 1985; Shibasaki & Hallet, 2006; Taylor, 1978), in that the increased speed of stimulus decreases the stimulus latency of the BP. In the current study, this is shown by the early BP of the reduced time constraint not being apparent until after the full-time constraint, and before the onset of the movement. However, unlike our hypothesis, the BP of the reduced time constraint condition also showed a larger magnitude as seen by Freude et al., (1988). Although this result has been found in prior studies, the result is by no means universal (Patil & Kochhar, 2016; Benecke et al., 1985; Shibasaki & Hallet, 2006; Taylor, 1978). The accuracy between the two trials was also shown to be insignificant.

Although the present study was carefully designed and thought through prior to the experiment development, there were multiple limitations to the study that interfered with the production of reliable results and conclusions. Some of the restrictions that we encountered during the data collection phase of the study included difficult environmental factors, as well as limitations of the apparatus and task software. The room that the task was completed in was oftentimes loud, with 14-17 people in the room at one time. This created an environment that was frequently distracting during data collection and could have a significant impact of the reliability of the data. In addition to the environment, the apparatus was not a typical EEG, but a Muse headband as previously mentioned. This device contains five primary electrodes that are located over the ventral portions of the frontal and parietal regions of the head, while the BP is generated thus generally measured around the central gyrus. While the Muse has been validated as an EEG measuring tool by prior research, it has not been validated for measuring BP (Krigolson et al., 2017). This and the smaller number and non-central location of electrodes likely makes the Muse a less precise tool for measuring BP using EEG. In addition to the hardware of the Muse, there were also potential inconsistencies to the data due to varying head shapes and hairstyles that result in insecure skin-electrode connections. The software that ran the task was also a limiting factor due to several bugs including visual feedback not displaying correctly, which would severely impact the participant’s accuracy on subsequent trials. If even a few of the aforementioned limitations were managed, the outcomes of the experiment would not only be more consistent with existing literature, but would also be reliable and show an accurate representation of our findings.

Our results add to the theory that each different visual stimulus has different effects on brain premotor areas when preparing a motor task. The stimulus latency of the BP could have implications on reaction time. For example, the BP must have a minimal length because the brain can only process information so fast. This speed could be the limiting factor on how fast the body can react. Moreover, the processing of perception (vision/sensory information) during a motor production could be considered when treating patients with motor diseases (e.g. Parkinson's Disease, Huntington's Disease, Cerebellar Disease, etc.). Effects on connections in afferent and efferent pathways during reaction type processes from neural connections from the brain to motor output could be a/the impairment of the initiation of movement, or a neural disconnect in a hybrid model of motor command (i.e. inverse and forward models). This being said, with validation of MUSE for BP research, our data could be used for future research on motor diseases and potential treatment methods.

Conclusion

As clearly shown in our results, the latency of the BP is shortened when the speed of the stimulus is increased. This effect on the BP is caused in short, because the brain doesn't have as much time to prepare the motor task with a faster stimulus. Future research could examine how the BP effects people with motor illnesses or disabilities, which could potentially change how we view these health conditions.

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