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Effects of Pulsed Electromagnetic Field on Reactive Performance

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Abstract

Pulsed electromagnetic field (PEMF) stimulation has been widely used in clinical settings for injury recovery and pain reduction; however, little is understood on its ability to modulate cortical activity, specifically in enhancing reactive performance. We hypothesized that stimulation of the FpZ site (Brodmann areas 10, 11, and 32), would upregulate activity in the prefrontal cortex, namely, the attentional network, which controls volitional movement. Twenty healthy subjects completed six trials on the Dynavision D2 interactive light board to establish a baseline for reactive performance (10 experimental and 10 sham). All participants donned a Bellabee wearable device and underwent (or did not undergo, if designated to the sham condition) 40 min of beta stimulation at the 10-20 FpZ location. Six trials were completed again after stimulation. A paired *t*-test revealed significant differences in the visual ($p = .003$) and physical ($p = .011$) components for the experimental condition. A student's *t*-test revealed the motor component to be significant ($p = .023$) when evaluating the postreaction time between the two conditions. Our findings suggest that a single dose of PEMF stimulation was sufficient to elicit significant changes in increasing reactive performance.

Keywords: T-PEMF; electromagnetic stimulation; perceptual motor speed; reactive performance

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Introduction

Characterization of interventions that elicit desirable perception, cognition, and action outcomes is crucial for optimizing the input-processing-output schema that defines the human operating system (HOS; Durkee et al., 2013). Increasing efficiency via augmentation of human perceptual and cognitive performance can be achieved by modulation of an individual's perceptual-motor processing, attentional resource allocation, and reaction timing, which resultantly produces considerable positive impacts with respect to an individual's readiness, workload, and recovery (Parsons et al., 2016).

Perception-reaction responses have been largely defined as an autonomic function, governing perceptual processes, including, action understanding and allocation of attentional resources (Parasuraman et al., 2009). Reactivity responses are governed by neuromuscular processes, where the nervous system receives an input (external stimulus) that then sends an efferent signal, causing the body to output a response. Reaction time describes the duration in time to respond to the stimulus. Quantification of an individual's reaction time can provide insight into how an individual responds to a stimulus or event (Parasuraman & Galster, 2013). Furthermore, optimization of an individual's attentional network could result in significant positive implications for sports and military performance outcomes via the optimization of goal directed behaviors (Lepsien & Nobre, 2006).

Attentional modulation is largely controlled by the frontoparietal attention control networks in the brain

(Petersen & Posner 2012). The frontal lobes are known to be responsible for higher-level cognitive function including planning, decision-making, cognitive flexibility, attention, and memory (Friedman & Robbins, 2022). Recent evidence suggests that the entire frontal lobe (beyond the previously established premotor cortex Brodmann area 6) is involved in premotor action such as planning and regulating higher-level motor skills (Fine & Hayden, 2022).

The 10-20 location FpZ lies over the medial prefrontal cortex (PFC) and consists of Brodmann areas (BA) 10, 11, and 32. These neuroanatomical locations play a critical role in analyzing and encoding task-relevant information and exhibiting cognitive control (Friedman & Robbins, 2022; Miller & Cohen, 2001). BA 10 (rostral PFC) is found to be active during simple and complex cognitive tasks involving planning and judgment (Koechlin et al., 1999), memory (Burgess et al., 2001), problem-solving (Christoff et al., 2001), and motor learning (Jenkins et al., 1994). Damage to BA 10 has been associated with decreased performance in time-based memory tasks (Burgess et al., 2013). BA 11 is anatomically inferior to BA 10 and is part of the orbitofrontal cortex (OFC) which is active during decision-making and plays a role in processing reinforcement and in working memory (Elliott et al., 2010). BA 32 is considered part of the ventromedial PFC and cytoarchitecturally defined as the dorsal anterior cingulate gyrus. This region has implications in decision-making and initiating goal-directed behaviors (Bechara et al., 1994; Holroyd & Yeung, 2012).

There exists an extensive amount of literature exploring the optimization of reaction time; however, little is understood regarding the modulation of key variables that promote increased perceptual-motor processing to increase reactive performance. One potential intervention used for modulating cortical activity, and subsequently, performance-related outcomes, is pulsed electromagnetic fields (PEMF). PEMF uses electromagnetic currents to induce restorative changes within the tissue at the cellular level. It has been shown to reduce inflammation after soft tissue injuries (Rasouli et al., 2012) and is FDA approved for treating pseudoarthrosis, complications from diabetes mellitus, delayed wound healing, pain, and neurodegenerative disorders (Funk, 2018). Though the majority of PEMF literature surrounds injury recovery, there are strong indications for use of PEMF in performance enhancement. Specifically, PEMF is used transcranially (T-PEMF) as a form of noninvasive brain stimulation; this type of neuromodulation introduces a weak electromagnetic current to the cortex and enhances cortical excitability (Capone et al., 2009). The pacing of the magnetic pulses may be used to help steadily guide the cortex into more synchronous, regulated rhythms to target performance-related cognition via transcranial magnetic stimulation (Fuggetta et al., 2005; Wang 2010); however, little is understood about the effects of transcranial PEMF stimulation.

This present study aimed to evaluate the effect of PEMF stimulation at increasing reaction time. It was hypothesized that due to the high frequency stimulation at the FpZ site, participants that received stimulation would have faster reactive performance. To our best knowledge, no present studies have examined the effect of PEMF stimulation on reactive performance in healthy populations.

Methods

Participants

A total of 21 healthy adults participated in the study; 11 participants received stimulation, and 10 participants were given a placebo. One participant from the placebo group had to be excluded from analysis resulting in a final count of 11 participants receiving stimulation and 9 participants given a placebo. The unequal number of participants in each group was a result of participant noncompliance. Prior to participation, all individuals completed a written informed consent that was approved by the West Virginia University Institutional Review Board (Protocol #: 2112489062); all procedures abided by the Declaration of Helsinki Guidelines. Participants were excluded from the study if they met any of the following exclusion criteria: has a metallic or electronic implanted device, currently on antihistamines or medication for attentional deficit disorders, those that were pregnant or trying to become pregnant, and those with histories of open skull traumatic brain injury, hemiparesis, epilepsy, seizures, orthostatic hypotension, Bell's palsy, or cranial nerve dysfunction.

Study Design

Participants were randomly assigned to the experimental or sham group. The Dynavision Reaction Test (defined below) procedure was explained to all participants. After the assessments of baseline perceptual motor speed and accuracy, the participants underwent (or did not undergo if assigned to the sham group) 40 min of stimulation using the commercially available, Bellabee device (Bellabee, Austin, TX). To keep the participants' focus and limit discrepancies, all participants completed up to 15 word searches during the 40 min. Then the participants completed the Dynavision Reaction Test to assess pre-post performance outcomes.

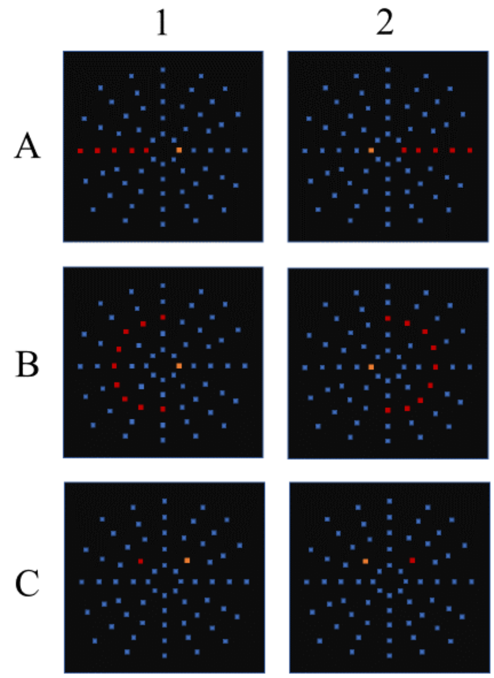
Reactive Performance

Reactive performance was assessed using the Dynavision D2 board (Dynavision Global Holdings LLC, West Chester, OH) which contains a total of 64 buttons arranged in five concentric rings. Each participant completed a total of three reaction tests with each hand, each containing a total of six trials. The participants were instructed to hold down a predefined reference button until they saw another light appear at a different location on the board, at which point they would subsequently release the reference button and hit the light as quickly as possible. Arrangement of the light patterns varied amongst the three trials, where the lights were arranged in the following patterns for trial 1, 2, and 3, respectively: straight line, half-circle, and two options. Please refer to Figure 1 for details. The Dynavision automatically outputs the physical, visual, and motor reaction times. The physical reaction time is a summation of the visual and motor reaction times, which represent the time the light illuminated to the moment that the reference button was released, and the time from the release of the reference button to the dismissal of the light, respectively.

Statistical Analyses

Data analysis and visualizations were produced in R (R Foundation for Statistical Computing, Vienna, Austria), where alpha levels were set *a priori* at 0.05. Paired *t*-tests were performed to determine differences in pre- and postsham and experimental average reaction times. Student's *t*-tests were performed to assess the difference between poststimulation average reaction times in sham versus experimental conditions. Each of the measured differences met the assumption for a normal distribution, which was determined by the Shapiro-Wilk goodness of fit test.

Figure 1. *Arrangement of Light Patterns on the Dynavision D2 Board for (A) Straight Line Condition, (B) Half-Circle Condition, and (C) Two Options Condition*.



Note. Each trial was repeated five times with the participants' dominant and nondominant hand.

Results

All reaction times were averaged across all the trials and configurations. Average reaction times for each component (physical, motor, and visual) and each condition (experimental, sham) can be found in Table 1 below.

A paired *t*-test was conducted to examine pre- versus poststimulation averaged reaction time for the sham and experimental conditions. There were no significant differences in visual, motor, or physical reactive performance in the sham condition. However, there existed significant differences in the visual (p = .003) and physical (p = .011) components, but not the motor component (p = .190) for the experimental condition.

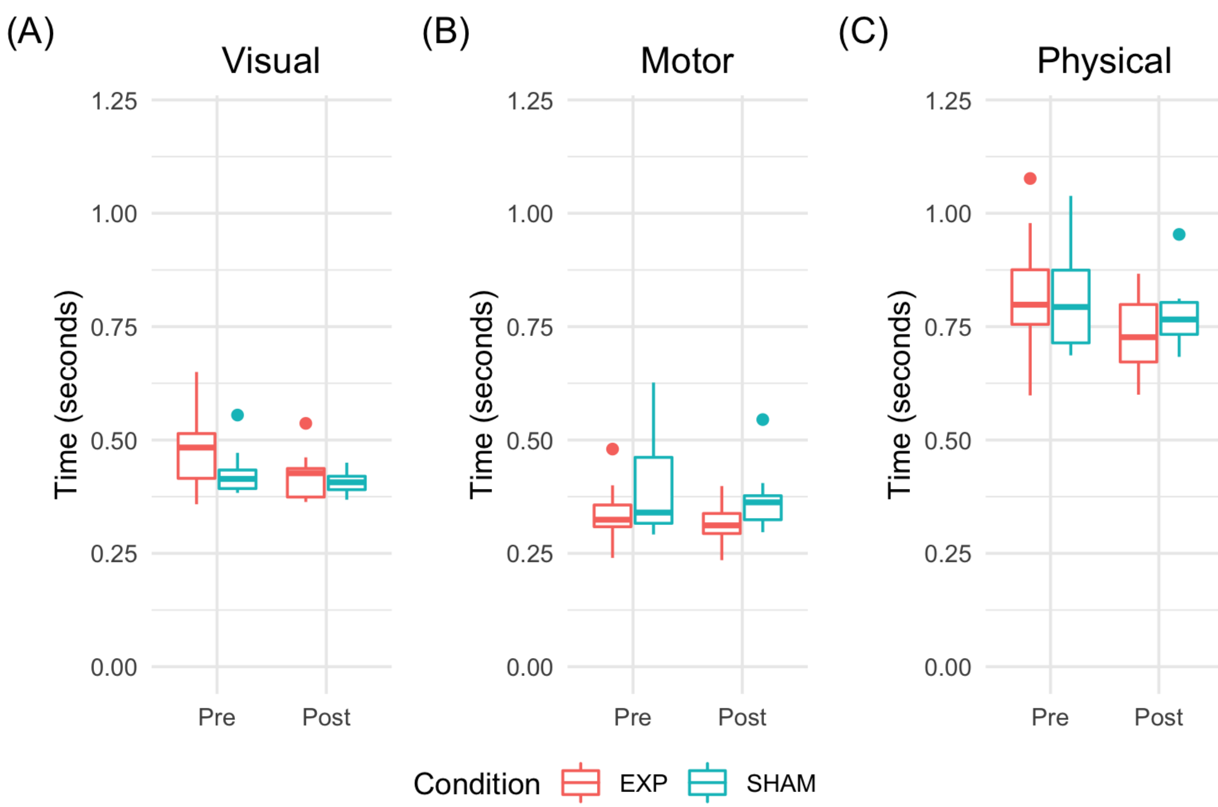
Table 1

Reaction Times for Physical, Motor, and Visual Components of Dynavision Reaction Test Between SHAM and EXP Groups

Condition	Pre/Post	Physical	Motor	Visual
Experimental	Pre	0.82 ± 0.13	0.34 ± 0.07	0.48 ± 0.09
	Post	0.74 ± 0.09	0.32 ± 0.05	0.42 ± 0.05
Sham	Pre	0.82 ± 0.13	0.39 ± 0.11	0.43 ± 0.05
	Post	0.77 ± 0.08	0.37 ± 0.07	0.41 ± 0.03

A student's *t*-test examining the postreaction time between the sham and experimental condition was found to be significant for the motor component (p = .023), but not the visual or physical components p = .348 and p = .174, respectively). As shown in Figure 2, reaction times for the experimental condition were found to be faster in the visual and physical components.

Figure 2. *Reaction Times for Experimental and Sham Conditions*.



Note. Organized by (A) visual, (B) motor, and (C) physical components of the Dynavision Reaction Time Test.

Discussion

This study aimed to examine the effects of cortical PEMF stimulation on reactive performance. Findings suggested that individuals who received 40 min of stimulation at the FpZ 10-20 site had significantly quicker reaction times than their sham counterparts. Compared to other reactive performance studies (Bagurdes et al., 2008; Kwak et al., 2020), this is the first study of its kind to examine the effects of deliberate modulation on the attentional network, using a form of external stimulation. Our findings suggest positive trends in reactive performance, which we attribute to three of our reported results. First, there were no significant differences between pre- and postreaction times in the sham condition. This suggests that a learning effect did not play a predominant role in reactive performance, establishing more credibility to the effectiveness of PEMF. Second, the aforementioned conclusion is further supported by the significant difference in postsham versus experimental reactive performance. Namely, individuals who received stimulation demonstrated quicker reaction times. Lastly, the pre- versus postreaction times were significantly different in the physical and visual components of the experimental condition, following stimulation.

Although pre- vs. poststimulation reaction time was significantly different in the experimental condition when averaging across all three components (visual, physical, and motor), when examining the components independently, the motor component did not exhibit any significant differences. The visual and motor components of the Dynavision reaction tests were defined as the time the light was illuminated to when the movement was initiated and the initiation of movement to the successful dismissal of the light, respectively, whereas the physical component was the summation of the visual and motor components. As shown in Figure 1 and Table 1, the visual component drives approximately half of the total summative time in the physical component. This suggests that PEMF stimulation may have more significance on the processing component of reactive performance rather than motor speed itself. One possible reason could be the target location. Namely, the anterior cingulate cortex controls volitional movement, and although its location is not superficial, cortical excitability at the FpZ site could potentially upregulate its effect at the BA 32 location which may play a role in the anticipation and detection of targets.

Shifting individuals towards peak performance via training or external forms of modulation, such as cortical PEMF stimulation, could have widespread implications in human performance settings; opening the door for use in populations (e.g., athletes, warfighters, etc.) where enhanced reactivity is highly sought. Enhancing perceptual-motor processing could aid in improving reaction time, thus optimizing cognitive loading, motor coordination, and ultimately resulting in injury prevention.

We envision that this preliminary study will be the first of many in understanding the effects of cortical PEMF stimulation on performance-based outcomes. The results obtained from this study are not intended to make conclusions on the use of cortical PEMF on individuals to enhance reactivity, but rather to demonstrate the existence of positive effects from stimulation. Future studies examining the prolonged effects of stimulation alongside subjective measures, quantitative electroencephalography (qEEG), or other performance-based measures (physiological trends, accuracy, etc.) to corroborate the findings from this study are warranted.

Despite the limited and unequal sample size, the results found in this study have demonstrated positive trends in reaction timing related to PEMF stimulation at the FpZ 10-20 site. To our best knowledge, this is the first study to examine the effects of cortical PEMF stimulation related to a performance-based outcome. These preliminary findings suggest that PEMF could provide a low-intensity, cost-effective, and user-friendly solution to regulating cortical activity in nonlaboratory environments.

Author Disclosure
The authors have no disclosures.

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