Manipulating Paradigm and Attention via a Mindfulness Meditation Training Program Improves P300-Based BCI.

Daniel Ryan Berry
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Manipulating Paradigm and Attention via a Mindfulness Meditation Training Program Improves P300-Based BCI

A thesis
presented to
the faculty of the Department of Psychology
East Tennessee State University

In partial fulfillment
of the requirements for the degree
Masters of Arts in Psychology

by
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August 2011

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ABSTRACT

Manipulating Paradigm and Attention via a Mindfulness Meditation Training Program Improves P300-Based BCI

by

Daniel R. Berry

To date, only one study has situationally bolstered attentional resources in an effort to improve P300-BCI performance. The current study implements a 4-week Mindfulness Meditation Training Program (MMTP) as a nonmedicinal means to increase concentrative attention and to reduce lapses of attention; MMTP is expected to improve P300-BCI performance by enhancing attentional resources and reducing distractibility. A second aim is to test the efficacy of the checkerboard paradigm (CBP) against the standard row-column paradigm (RCP). Online results show that MMTP had greater accuracies than CTRL and that CBP outperformed the RCP. MMTP participants provided greater amplitude positive target responses, but these differences were not statistically significant. CBP had greater positive amplitude peaks and negative peaks than RCP. The discussion focuses on potential benefits of MMTP for P300-based BCIs, provides further support for the construct validity of mindfulness, and addresses future directions of the translational applicability of MMTP to in-home settings.
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CHAPTER 1

INTRODUCTION

Farwell and Donchin (1988) recognized that the P300 component of the event-related potential is relatively robust (Donchin, 1981; Fabiani, Gratton, Karis, & Donchin, 1987; Pritchard, 1980; Sutton, Braren, Zubin, & John, 1965). They used this knowledge to create a P300-based BCI spelling program by collecting scalp recorded electroencephalogram (EEG) from participants who responded to time-locked stimuli on a computer screen. Although still in its incipient stages, their BCI program allowed participants to spell words on a computer without any muscular output on a keyboard (i.e., using only scalp-recorded, P300 responses) by focusing attention to intended target items. Importantly, a number of studies report that people with ALS can communicate via P300-based BCIs (Kubler et al., 2005; Kubler et al., 2009; Nijboer et al., 2008; Sellers & Donchin, 2006; Sellers, Vaughan, & Wolpaw, 2010).

Although BCIs provide viable means for communication in late stages of ALS where people are rendered locked-in to their bodies, BCIs are not without their problems. For instance, researchers are still unsure as to the optimal means of stimulus presentation (e.g., Guger et al., 2009; Hong, Guo, Lui, Gao, & Gao, 2009; Salvaris & Sepulveda, 2009; Townsend et al., 2010). Also, BCI operation requires a great deal of self-control (Birbaumer et al., 2000), which taxes attentional resources. Collectively, these problems undermine the speed and accuracy of the system and give rise to a great deal of frustration to the user. In this research I propose that increases in users’ attentional resources may be one means to this end. Drawing from past research, Mindfulness Meditation Training Programs (MMTP) offer nonmedicinal means to increase attentional focus and sustained attention capabilities that could translate to faster and more accurate P300-based BCI performance (Lakey, Berry, & Sellers, 2010). Although a number
of definitions of mindfulness exist, all converge to describe mindfulness as an attentional construct that entails awareness of and attention to the present moment (Brown & Ryan, 2003) or “flexible, yet purposeful, attention to the present” (Brown, Ryan, & Creswell, 2007, p. 212). All people possess some degree of trait mindfulness, though they vary in the general tendency to be purposefully cognizant of their immediate experience (Brown & Ryan, 2003). However, situational or state level training, via yoga or meditation for example, serves to increase individuals’ attention to and awareness of the present moment (Kabat-Zinn, 1990, 2003). In this research I aim to capitalize on the fact that mindfulness training or induction increases present-moment attention and awareness. Specifically, I explore the extent to which a 4-week MMTP may attenuate errors that occur while using the P300 speller. I believe MMTP will deter the extent to which lapses of attention such as stimulus independent thought (mind wandering; Smallwood & Schooler, 2006) and nontarget flashes (distractions) on the BCI contribute to user errors.

Before detailing the study in which I examine the possibility that implementing mindfulness via MMTP will harness participants’ attentional resources and enhance BCI performance, first I will provide a background for P300-based BCI technologies. This background includes a review of event-related potentials (ERPs), detail about the P300 component of the ERP, and the manner in which BCIs use ERPs. Subsequently, I present a broad review of the development of P300-based BCIs, the systematic problems associated with their use, and researchers’ attempts to improve the speed and accuracy of the P300-based BCI. Thereafter, I briefly define the construct of attention by outlining its proposed components, and report findings indicating the importance of attention in the operation of P300-based BCIs. Finally, I define and describe the construct of mindfulness and its potential improvements to
P300-based BCIs. In the process, I will review the measurement of both dispositional and state mindfulness, explain ways in which mindfulness is induced, and I will draw from theoretical and empirical research to describe the benefits of mindfulness and the manner in which a 4-week MMTP serves to increase state-based mindfulness, thereby improving P300-based BCI performance.
CHAPTER 2
BRAIN COMPUTER INTERFACES (BCIs)

Definition of BCI

BCIs are communication and control devices that allow users to execute computer
commands via the input of intentional brain signals (Wolpaw & Birbaumer, 2006). Users are
thereby capable of communicating by nontraditional means (e.g., spoken words). Currently, three
independent classes of BCIs exist. Invasive single or multiple cell recordings have been used
successfully by primates to move computer cursors or to control the grasping and movement of a
robotic arm (Donoghue, 2002; Nicolelis, 2003; O’Doherty, Lebedev, Hanson, Fitzsimmons, &
Nicolelis, 2009). Single or multiple cell recordings also have been preliminarily tested on
humans (Hochberg et al., 2006). Discovering another invasive means for recording, Leuthardt,
Schalk, Wolpaw, Ojemann, and Moran (2004) demonstrated that electrocorticographic (ECoG)
signals, recorded from an array of electrodes usually implanted above the dura mater can be
translated into computer commands without muscle artifacts and interference from the skull.
Noninvasive electroencephalogram (EEG) can be used to record brain signals from the scalp
(e.g., Farwell & Donchin, 1988). Though invasive options exist, the beneficiaries of BCIs may
find more practical use of EEG recorded brain signals for the implementation of the device is
noninvasive. Huggins, Wren, and Gruis (2010) found that 84% of people with ALS were
interested in noninvasive options, and only 41% were willing to undergo surgical electrode
placement.

As an extension of the definition of BCI, Wolpaw, Birbaumer, McFarland, Pfurtscheller,
and Vaughan, (2002) reported five essential components to creating a BCI (see Figure 1)
including: one, a signal acquisition method is used (e.g., EEG) to record brain signals, and these
signals are digitized after recording; two, a feature extraction component during signal processing that uses these raw digitized signals and converts them into a useful device command; three, a translation algorithm decodes the extracted signal features into device commands or orders; four, a device output, in the form of an overt command or control function (e.g., word processing or movement of a robotic arm) is administered by the BCI; and five, an operating protocol defines how the system is turned on and off, and also defines whether the communication is continuous or discontinuous, and the message transmission is triggered by the system or the speed of the user-computer interaction. These five components work in conjunction to restore overt control and communication for people with severe neurodegenerative diseases. The literature review in this study focuses on the implementation of the P300 component of the ERP to execute word processing computer commands, in a program called the *P300 speller*.

*Figure 1.* This figure shows a schematic of the five essential components of a brain-computer interface system. Going clockwise from the bottom left to the bottom right of the figure, the schematic outlines the five components from Birbaumer et al. 2002. (Figure modified from Leuthardt et al., 2006).
Electroencephalogram and Event-Related Potentials

Berger (1929) discovered that placing silver foil electrodes to the scalp and recording electrical currents with a string galvanometer could measure electrical activity from the scalp as small as one ten thousandth of a volt; this method was termed the electroencephalogram (EEG). EEG is a gross measure of the electrical activity collected from various points from the surface of the scalp (e.g., Berger, 1929). More specifically, the potentials recorded from the scalp are generated in the pyramidal cells located in layers four and five of the cortex; these pyramidal cells receive signals from and feed back to the thalamus, producing corticothalamic “current loops”, which resemble a rhythmic pattern that is generated in the output of an EEG (Hugdahl, 1995).

Initially, Berger’s findings were controversial, but the phenomenon of EEG was supported when Davis and Davis (1936) recorded the first event-related potential (ERP). An ERP reflects patterns of underlying neuronal activity that can be specific to modalities (e.g., auditory, visual, tactile) and are evoked by temporary stimuli; the responses to these stimuli are summed and volume conducted to scalp electrodes (e.g., Kayser & Tenke, 2003; Rose & Woosley, 1949). Computerized ERP recording techniques were introduced by Galambos and Sheatz (1964), which initiated the discovery and classification of components. The component structure of an ERP is conceived as the electrophysiological correlate of underlying neuronal activity that is task dependent and manifests a specific time course and topography (e.g., Tenke, Schroeder, Arezzo, & Vaughan, 1993).

ERPs may be classified by their polarity (positive or negative), their time course (latency), their ordinal occurrence (brainstem evoked responses; BERs), and/or their topography. Furthermore, ERPs may occur in the absence of a stimulus or prior to a stimulus. One example
of ERPs occurring prior to a stimulus is the Contingent Negative Variation (CNV) or the readiness potential. Walter, Cooper, Aldridge, McCallum and Winter (1964) first reported the CNV as an anticipatory component that is elicited in the waiting time between a warning stimulus or prestimulus cue and a target stimulus. Component distinctions are also made between the exogenous or endogenous nature of a stimulus (Donchin, Ritter, & McCallum, 1978). Donchin et al. (1978) contend that exogenous components are unconscious responses to a stimulus or responses that are not affected by cognitive processes. For example, the N100 is thought to be generated in the auditory cortex of the temporal lobe (Vaughan & Ritter, 1970), and it is modulated by stimulus properties. In contrast, endogenous responses reflect higher cognitive processing and generally occur later in the recording epoch (Donchin et al., 1978).

Discovered by Sutton et al. (1965), the P300 component is an endogenous component that occurs when participants are uncertain of an expected stimulus. Sutton et al. (1965) presented brief clicks and flashes of light to participants, and stimuli were flashed and clicked randomly between two different categories including an attended target and ignored standard (nontarget). When participants were uncertain of the target, a positive-going deflection would occur in the waveform reaching peak amplitude about 300 milliseconds after the presentation of the target stimulus. As previously stated, the present study focuses on the implementation of the P300 component in BCIs. As such, the P300 is outlined in greater detail in the following section.

The P300 Component

The P300 is a positive deflection in the EEG that peaks approximately 300 milliseconds after the presentation of a specific target stimulus that has a low probability. The P300 manifests a distinct amplitude, poststimulus latency, and scalp distribution of time-locked and averaged responses; typically, the response is largest at posterior scalp locations (electrode Pz) and
decreases at more anterior electrode locations along the midline (e.g., electrode Cz and Fz; see
Figure 2; Donchin, 1980; Fabiani et al., 1987; Pritchard, 1981; Sutton et al., 1965). Donchin and
Coles (1988) further extended the definition of the P300 by describing the task in which the
component is elicited. Usually referred to as the oddball task, four conditions must be met by the
task: one, there must be a random or quasi-random sequence of stimuli presented to a participant;
two, there must be some classification rule applied separating stimuli into at least two categories
(targets vs. nontargets); three, the participant must attend to and mentally record one specific
category out of the two categories. In other words, the participant will categorize one item as a
target and attend to that target, while ignoring the nontarget; four, one of the categories, usually
the targets, must be presented infrequently. For example, in a visual oddball paradigm,
participants may be asked to attend to flashing stimuli in the center of a computer monitor. Two
characters may occur: an infrequently occurring “X” or a frequently occurring “O”, and the
participant mentally records all every “X” he or she notices.

Figure 2. A) An X-O oddball sequence. B) P300 responses to a time-locked oddball stimulus at electrode location
Cz, Pz and Fz (positive amplitude is oriented downward). Notice the sharp positive target response (red)
approximately 350 milliseconds poststimulus. This peak is distinct from the nontarget response (blue), for it
represents an endogenous response to a rare meaningful stimulus.
Early research on the P300 showed that the amplitude of the component is modulated by a participant’s “expectancy” of a stimulus (Squires, Wickens, Squires, & Donchin, 1976). Expectancy is comprised of two components: a priori probability of a stimulus and stimulus sequence. Squires et al. (1976) confirmed that a priori stimulus expectancy is negatively related to P300 amplitude. That is, as targets become less probable, the amplitude of P300 responses increase. Additionally, P300 amplitude is thought to be related to humans’ decaying memory of prior events in a sequence of stimuli. More specifically, when a participant is directed to focus and mentally record the letter X (target) in an X-O oddball paradigm, if the letter X occurs consecutively (e.g., “O, X, X, X”), then the amplitude associated with the P300 will reduce, for the X has become more probable than the O. Furthermore, if an O was to follow in the previously described sequence (e.g., O, X, X, X, O), that O would elicit a greater P300 amplitude, though it is not the intended target. Duncan-Johnson and Donchin (1977) varied target probability between .10 and .90 increasing in increments of .10 (see Figure 3) and found that 10% to 20% probability provided the highest amplitude P300s. Duncan-Johnson and Donchin (1977) also confirmed that a priori stimulus probability was negatively correlated with P300 amplitude, and stimulus sequences in second order pairs (e.g., XX, OO, XO, OX) modulated P300 amplitude, such that when targets followed nontargets, greater amplitudes were observed. Squires Petuchowski, Wickens, and Donchin (1977) included third, fourth, and fifth order groupings and confirmed that P300 amplitude was affected by memory of specific events related to the structure of sequencing.
Figure 3. This figure shows modulation of P300 amplitude at varying a priori stimulus probabilities in an auditory task. Notice that P300 amplitude increases as a priori stimulus probability decreases (Figure modified from Duncan-Johnson, & Donchin, 1977).

Donchin and Coles (1988) suggest that P300 latency is a function of the participant’s evaluation of the stimulus. That is, the longer it takes a participant to evaluate the significance or novelty of a stimulus, the longer the component latency. Latency of the P300 is independent of reaction time or other behavioral responses (McCarthy & Donchin, 1981). McCarthy and
Donchin (1981) found that stimulus discriminability, or the ability to discriminate between two similar stimuli, affected P300 latency. For example, it is more difficult to distinguish between red and orange stimuli than red and blue, and this is reflected by longer latency P300 responses. Additionally, choice reaction time was determined by both stimulus discriminability and stimulus-response compatibility, or the degree to which a set of stimuli and associated responses are naturally related to each other.

**P300-Based BCIs**

As previously stated, Farwell and Donchin (1988) pioneered the advancement of a mental prosthetic device called the P300 speller. Using a 6x6 matrix of alphanumerical characters, Farwell and Donchin (1988) modified the oddball paradigm by flashing entire rows and columns of the letters. Thus, each character flashed 16.7% of the time. During the study participants were required to focus on a specific letter and mentally record each time it flashed. Consequently, each time a row or a column containing the participant’s intended letter would flash, a P300 should be elicited in response to that target. After a short calibration phase, a translation algorithm classified target and nontarget P300 responses via stepwise discriminant analysis (SWDA, described below). This SWDA was applied to subsequent online testing trials where participants were directed to copy-spell a word one character at a time. The P300 speller allowed able-bodied participants to intentionally select letters on a computer monitor, and due to the robust nature of the P300, the training time was relatively short. In comparison, other BCI methods, incorporating μ or β rhythms, require users to control the amplitude of these rhythms, thereby allowing the user to intentionally move a cursor about a computer monitor (Wolpaw, McFarland, & Vaughan, 2000). These rhythms can take several training sessions to allow sufficient communication.
Twelve years later, Donchin, Spencer, and Wijesinghe (2000) replicated and extended the findings of Farwell and Donchin (1988) by analyzing the P300 speller on- and offline. Online testing typically entails manipulation of stimulus presentation (i.e., number of flashes presented to the participant) and tests accuracy of the participant in real time, whereas offline accuracy is measured when the study implements a classification algorithm to predict the accuracy of a participant’s target responses during a task. Townsend et al. (2010) reported that offline measures (e.g., leave-one-out cross-validation) do not account for temporal dependency required for online classification, and that offline measures can only indicate predictive performance. Thus, while offline accuracy is informative and may demonstrate that a paradigm will work, only online testing can more definitively establish the efficacy of a paradigm. Donchin et al. (2000) reported that participants who attempted to spell items using the row column paradigm were 56% accurate online, and offline analyses using a bootstrapping technique predicted that an accuracy of 90% and an information transfer rate of 7.8 bits per minute was possible. What was promising was that a majority of the errors occurred in adjacent cells (i.e., 92% on target or within adjacent cells). For example, if a participant wished to spell the letter “D”, then “C” or “E”, which are adjacent to the “D” in the 6x6 matrix, might be a common error. Although promising, these findings indicated a potential flaw with the RCP, such that adjacent characters may cause errors by distracting attention away from the target. Nevertheless, these initial studies laid the groundwork for the P300-based BCI.

Difficulty in replicating the strong performance of able-bodied participants in an in-home setting typifies the state of the research on developing a general purpose BCI. However, a number of studies have reported promising results with ALS patients (e.g., Hoffmann, Vesin, Ebrahimi, & Diserens, 2008; Kubler et al., 2005; Nijboer et al., 2008; Piccione et al., 2006;
Sellers & Donchin, 2006). Most recently, Sellers, Vaughan, and Wolpaw (2010) demonstrated the long-term benefits for a user with ALS. Results indicate that accuracy remained at 83% over a period of 2.5 years, and qualitative self-report suggest that the BCI user has restored independence in social interactions at home and at work. Most importantly, long-term use of a BCI may contribute significantly to quality of life for people with severe neurodegenerative diseases. Though these findings offer hope for severely disabled users, recent research has focused on improving the speller through several avenues.

**Improvements to P300-Based BCIs**

As means to improve P300-based BCIs, researchers have aimed at optimizing electrode montages (Krusienski, Sellers, McFarland, Vaughan, & Wolpaw, 2008), and comparing signal processing methods (Krusienski et al., 2006). Additionally, nonvisual modalities have been tested as an avenue for improved spelling performance; currently, auditory-based P300 spellers are being improved (Furdea et al., 2009; Klobassa et al., 2009; Kubler et al. 2009; Sellers & Donchin, 2006; Sellers, Kubler, & Donchin, 2006), and tactile BCIs are in their nascent stages (Brouwer & Van Erp, 2010).

Traditional BCI research implemented midline electrodes leads (i. e., Fz, Pz, Cz) to classify target responses. Using a support vector machine classifier, Kaper, Meinicke, Grossekathoefer, Lingner, and Ritter, (2004) found that only 10 electrode positions were necessary for accurate classification. Most recently, Krusienski et al. (2008) collected 64-channel EEG from seven able-body participants who copy-spelled 36 characters within a 6x6 RCP matrix. Copy-spelling is most often used in P300 BCI testing, for it allows a more valid assessment for accuracy. Participants may also free-spell; free-spelling entails volitionally selecting letters and commands that have not been provided to the participant. Stated differently,
when free-spelling, the participant is in control of what he or she spells. Online and offline data assessed the optimal lead location from 19 electrodes using a stepwise linear discriminant analysis (SWLDA). Findings confirmed that online classification was best when using electrodes Fz, Cz, P3, P4, PO7, PO8, and Oz (see Figure 4). This study demonstrated that posterior-located electrodes contribute additional information to P300 classification. Additionally, no differences were observed when references were moved from the ear to a common average reference (CAR). Common average references take an average ERP from all channels and subtract each channel from that average. In contrast, referencing to a particular location, such as linked ears, linked mastoids, or the nose takes an average ERP from the reference site and subtracts all electrodes from that reference.

*Figure 4. The electrode montage used in Krusienski et al. (2006). Electrodes circled in green were used for classification of responses to time-locked stimuli on a P300-based BCI. The present study uses the same leads (Fz, Cz, P3, P4, PO7, PO8, & Oz) for classification (modified from Krusienski et al., 2006).*

Moreover, researchers have aimed to identify and improve the best classification techniques. Krusienski et al. (2006) established that SWLDA provides optimal training time and
the best target classification relative to competing linear and kernel translation algorithms.

SWLDA is a linear regression method that performs both forward and backward partial regression to select features of a subject’s waveform that best discriminate between target and nontarget responses. While several classification techniques such as support vector machines (e.g., Meinicke, Kaper, Hoppe, Huemann, & Ritter, 2002) and matched filtering (e.g., Serby, Yom-Tov, & Inbar, 2005) can provide sufficient P300 Speller performance, SWLDA outperforms these options. Krusienski et al. (2006) collected 64-channel EEG data from eight participants using a 6x6 row column paradigm, and tested the performance of five linear and kernel classification methods including Pearson’s correlation method (PCM), Fisher’s linear discriminant analysis (FLD), linear support vector machine (LSVM), SWLDA, and Gaussian support vector machine (GSVM). Krusienski et al. (2006) found that despite short training, PCM provided the lowest classification accuracies. Both LSVM and GSVM provided significantly better performance than PCM. However, Krusienski et al. (2006) noted that GSVM can over-fit data. Over-fitting can be a common dilemma with nonlinear classifiers because they are often able to model training data very accurately but can fail if the training data are not totally representative of test data. FLD and SWLDA provided optimal training time and the highest performance. SWLDA excels where FLD fails because with an insufficient amount of training observations FLD can deteriorate. SWLDA training is reasonably efficient because a terminating heuristic is implemented in such a way that suitable features are selected in a nonexhaustive manner.

Because little is known about the degeneration of visual perception in people with ALS and other severe neurodegenerative diseases, auditory P300-based BCIs have been tested by a number of researchers (e.g., Furdea et al., 2009; Sellers, Kubler, & Donchin, 2006). Sellers and
Donchin (2006) implemented a four-choice oddball paradigm in visual, auditory and combined visual and auditory modalities. Participants were presented with choices including yes, no, pass, and end. Results suggest that using an auditory-based BCI, particularly with spoken words, may be difficult for classification, for stimuli may be recognized in slower time courses. Similarly, Furdea et al. (2009) suggest auditory-based BCIs responses were accurately classified and produced high performance rates, but compared to the visual spelling system, users' information transfer rates were slower and their peak latencies of the auditory-evoked ERPs were delayed. Additional problems with auditory paradigms exist. For example, participants have reported more difficulty concentrating on an auditory task (Kubler et al., 2009).

Though auditory paradigms have provided, for the most part, inferior results to visual paradigms, some studies have shown promise in the advancement of auditory-based BCIs. For instance, using a high-throughput auditory paradigm, Klobassa et al. (2009) reported equivalent accuracy to an auditory and visual paradigm in which visual stimuli were systematically removed after initial sessions. Also, combining an auditory paradigm with spatial location (i.e., multiple speakers placed around the participant) can yield an information transfer rate (ITR) of 17.39 bits per minute, thus providing a fast BCI that solely relies on the auditory modality (Schreuder, Blankertz, & Tangermann, 2010). Aesthetic advantages can be realized via tactile BCIs. Brouwer and Van Erp (2010) investigated a BCI based on EEG responses to vibro-tactile stimuli emitted from a belt situated around a participants waist. Though performance is inferior to visual and auditory-based systems, tactile BCIs may provide advantages to the user without taxing the visual or auditory system, and may be unnoticeable to other people. Currently, visual-based BCIs represent the best presentation method when moving from the laboratory to in-home clinical settings.
Errors in the Row/Column Paradigm (RCP)

Currently, two known classifications of errors exist with the RCP that slow communication and frustrate users. Specifically, these errors include adjacency errors (Fazel-Rezai, 2007) and double-flash errors (Martens, Hill, Farquhar, & Scholkopf, 2009; Woldorff, 1993). Adjacency errors occur in the RCP when participants are distracted by adjacent cells within the P300 speller matrix when they flash. In the RCP, stimuli are presented by flashing an entire row or column. Thus, if one’s target happens to be a “O”, both the column and row that contain the “O” elicit a P300 response when they flash. At the intersection of this row and column, the P300 amplitude of the “O” should be greater in amplitude than surrounding characters (see Figure 5); a classification algorithm will “recognize” the “O” as the intended target. However, at times, one of the four adjacent characters will be selected as the participant’s intended target character. These errors occur when adjacent nontarget rows or columns attract the attention of the participant producing a P300 response (Fazel-Rezai, 2007; Townsend et al., 2010).
Figure 5. A) A 6x6 RCP display. In this paradigm rows and columns are randomly intensified as indicated in column 3. B) Presents the average waveforms for all 36 cells within the speller matrix. In this case the target letter is “O” indicated by the red waveform within the cell. The blue waveforms are larger than surrounding cells, for they elicit a P300 when flashing simultaneously with the target character. Each of the responses in the cells represents multiple stimulus presentations. C) Overlapping waveforms; as indicated in the figure the red waveform indicates the target character, and the blue represent characters falling within the same row or column as the target character (Modified from Sellers et al., (2007)).
Double flash errors occur when a target item is flashed twice consecutively. Woldorff (1993) reported that when two stimulus presentation epochs overlap temporally, they can reduce the P300 amplitude or change its morphology. Martens et al. (2009) tested this finding in the RCP and found that, indeed, double flashes reduced P300 amplitude and changed P300 waveform morphology, and the change in waveform morphology increased classification errors in the P300 speller. Double flashes in the RCP are a product of a row flash followed by a column flash, or vice versa, when the target item is at the intersection of both row and column. For example, if the user is focusing on the letter “O”, it would be elicited by a row flash followed immediately by a column flash containing the “O”. Due to the rapid rate of intensification, double flashes can cause errors of two types: one, if the target item is involved in a double flash, the second flash may go unnoticed by the participant, so that it does not produce a P300 response; and two, even if the second flash is perceived, the P300 responses to the two flashes overlap temporally (Martens et al., 2009; Woldorff, 1993). The first P300 speller (Farwell & Donchin, 1988) could have as many as four consecutive flashes of an intersected target. Although current RCPs are programmed to have only two consecutive flashes of an intersected target, both adjacency and double flash errors still serve to undermine the speed and accuracy of the RCP.

Stimulus Presentation and Paradigm Improvements

While researchers have improved performance through assessing translation algorithms, electrode montages, and alternative P300 modalities, the greatest gains have come from manipulating stimulus properties and altering presentation paradigms. Allison and Pineda (2003) found that increasing matrix size provided greater P300 amplitudes; this was expected as amplitude is negatively correlated to a priori probability. That is, if the number of possible
character selections is increased, the probability of an intended character is reduced, thereby increasing peak P300 amplitude. Sellers et al. (2006) examined the effects of two different matrix sizes (3x3 and 6x6) and two interstimulus intervals—on the time in between the end of a flash and the onset of the next flash (ISI; 175ms and 350ms)—on BCI performance. Short ISIs (175ms) combined with larger matrices (6x6) provided the best user accuracy and highest P300 amplitudes. These findings helped to answer the previously debated findings in the literature.

One study suggested that longer ISIs would provide higher classification accuracy (e.g., Farwell & Donchin, 1988), whereas Meinicke et al. (2002) reported higher classification accuracies with shorter ISIs. Sellers et al. (2006) also indicated that individual differences play a role in classification performance and optimal stimulus properties may be user-specific. Thus, testing multiple matrix sizes and ISIs may be necessary for meeting user’s individual needs.

Salvaris and Sepulveda (2009) also manipulated stimulus properties by testing changes to the visual aspects of the RCP. The effects of differing foreground and background setups, symbol size, and inter-symbol distance were examined in six conditions. Researchers tested the efficacy of a black background with white characters, white background with black characters, increased symbol size using a black background, decreased symbol size using a black background, greater distance between symbols with a black background, and shorter distance between characters using a black background. Salvaris and Sepulveda (2009) found no clear subjective preferences among the eight participants in the study; however, white backgrounds provided the highest classification accuracies, and small symbol sizes yielded the lowest classification accuracies.

Research involving modifications to the RCP paradigm drastically increased over the last few years. Martens et al. (2009) developed a new stimulus presentation format referred to as the
flip stimulus. Flip stimuli consist of superimposed grey rectangles with a vertical or horizontal orientation, and each grey rectangle envelops one alphanumerical character within the matrix. An event corresponds to a 90 degree rotation of the superimposed rectangle, creating the perception of apparent motion. Martens et al. (2009) found that in comparison to the RCP flip stimuli provided less of a refractory effect than flashing stimuli. That is, when two targets overlapped temporally, flip stimuli did not attenuate the second P300 response as much as flashing stimuli in the RCP. While the flip stimuli produced smaller refractory effects, no significant differences were found for performance. In another apparent motion paradigm, Hong et al. (2009) showed comparable performance to the RCP using their “N200-Speller”. To achieve apparent motion Hong et al. (2009) embedded “buttons” located just below every character within a 6x6 matrix; participants were instructed to gaze at the buttons. Each button contained a vertical bar that was located on the right of the button, and this vertical bar was a specific color that did not occur in adjacent buttons. A stimulus event occurred when a vertical bar would move from left to right, thus eliciting a N200 or a visual evoked response. It is believed that the N200 is maximum at electrode locations associated with the extrastriate temporal-occipital areas, and other parietal areas. As expected, the N200-Speller provided different spatiotemporal characteristics, but the results presented in the study were examined with differing tasks (onset motion vs. modified oddball); thus, the differences in waveforms found by Hong et al. have limited utility, for the responses were collected with differing task demands. The N200-Speller did provide greater offline accuracy than the RCP, but no significant differences were found for information transfer rate.

Some researchers have believed that the grey to white flashing on a computer screen can induce discomfort; in an effort to attenuate this discomfort, Takano, Komatsu, Hata, Nakajima,
and Kanasaku (2009) examined the efficacy of a RCP speller with a chromatic flash pattern. Drawing from previous literature (Parra, Lopes da Silva, Stroink, & Kalitzin, 2007), Takano et al. (2009) tested the possibility that a blue to green flash pattern was safest, for researchers found it to be the most harmless for photosensitive epileptics. Given this knowledge, 10 healthy participants using an 8x10 matrix, viewed three different flash categories: one, a grey to white, where luminance was brighter when the characters flashed white; two, a blue to green flash pattern was used, where luminance was not brighter when the characters flashed to green; and three, a blue to green flash pattern, where luminance was brighter as characters flashed to green. Results demonstrate that the third condition, where participants saw a blue to green change, where the green character’s luminance was brighter, allowed for the highest offline accuracy compared to the other conditions; similar to Hong et al. (2009), no information transfer rate differences were reported. Guger et al. (2009) compared a single-flash paradigm (SFP) to the standard RCP. Using a 6x6 matrix, the SFP flashes only one character at a time, whereas the RCP flashes a total of six. While the SFP yielded greater amplitude P300 responses, presumably due to the elimination of flanking characters, accuracy was surprisingly lower (SFP = 77%, RCP = 85%). Guger et al. (2009) reported that participant fatigue may have contributed to the reduced accuracy, for a much longer period of time is required for character selection in the SFP, relative to the RCP. That is, it would require a total of 12 flashes to complete a sequence in the RCP, and 36 flashes in the SFP using a 6x6 matrix. Even if the SFP were to provide greater accuracy, it likely would always have slower information transfer rates because it takes three times as long to complete a sequence relative to the RCP.
The Checkerboard Paradigm

Most recently, Townsend et al. (2010) created the checkerboard paradigm (CBP) to reduce the adjacency and double-flash errors associated with the RCP. This system’s performance was compared to the RCP using 72-character 8x9 matrices. As a means to eliminate adjacency errors the checkerboard paradigm takes a 72-character matrix (8x9) and splits it into two 6x6 matrices via a superimposed CBP that the participant does not see. The CBP splits characters into either white or black matrices (see Figure 6). During a sequence the six virtual rows flash in the white matrix, followed by the black matrix in order from top to bottom. Then the six virtual columns flash from left to right (white then black). After each sequence of flashes the matrices randomly populate with characters, thereby eliminating adjacent flashes and presenting an apparently random sequence of flashes. The double flash problem is programmed out of the CBP by first flashing the 12 rows of the two matrices (white followed by black), and then flashing the 12 columns of the two matrices (white followed by black). Meaning at least 6 flashes and at most 18 flashes occur between characters in a particular sequence. The CBP significantly improved online accuracy 14% (91% in the CBP compared to 77% in the RCP). The RCP, however, provided no significant differences for information transfer rates (27.4 bits/min compared to 26.8 bits/min) prior to correcting for errors. Offline information transfer rates (practical bitrates) were higher for the CBP (23 bits/min compared to 16 bits/min). The CBP marks the greatest improvement to P300 speller performance to date but needs further validation and comparison in several experimental set-ups. Lou and Min (2010) have published a new paradigm similar the CBP that suppresses characters around the target character in a speller matrix. To achieve this end, characters were intensified in orthogonal Latin square pairs; these
pairs satisfied distance constraints so that no adjacent characters would flash. No performance data have been published on this paradigm.

Figure 6. A) The 8x9 row column paradigm with a row flashing. B) The checkerboard superimposes a black and white checkerboard over a standard row column matrix that participants are unable to see; this eliminates the possibility of adjacent flashes. The cells of each 6x6 matrix repopulate after a sequence. C) After programming the participant would see this 8x9 checkerboard paradigm with the same row flashing as in the 8x9 row column (modified from Townsend et al., 2010).
CHAPTER 3
ATTENTION

Definition and Neural Networks of Attention

Since the inception of experimental psychology, researchers have been interested in exploring the phenomenon of attention. Through introspection, James (1890) argued that everyone was familiar with the construct of attention and he broadly defined it as selecting some stimuli for evaluation while turning out other stimuli. While this explanation attempted to define a component of attention (selective attention; described below), almost 110 years later researchers are still unsure as to the appropriate operational definition of attention (Pashler, 1999). Although there is no agreed-upon definition of attention, Posner and colleagues (Posner, & Boies, 1971; Posner & Petersen, 1990) argue that attention is a cognitive neurobiological mechanism that entails three components specific to its function: orienting, signal detection, and alerting. In this paper I adopt Posner’s three-component model of an attention network that draws from behavioral, cognitive, and neurological evidence and relates this model to the operation of BCIs.

Posner and Petersen (1990) proposed an attentional model based on findings and developments in neuroscience (Hillyard & Picton, 1987; Raichle, 1983; Wurtz, Goldberg, & Robinson, 1980) that focused on the necessity of dividing the attention system into three functioning networks. The Posner model of attention suggests that the attention system of the brain is anatomically separate from other motor and sensory systems, but it does interact with other parts of the brain; also attention is carried out by a number of anatomical areas and it is not anatomically found in a single locus, nor is it a general function of the brain operating as a whole (Mesulam, 1981). The attentional system is divided into three networks that carry out the
functions of orienting to sensory events, detecting signals for focal conscious processing, and maintaining a vigilant or alert state (Kahneman, 1973; Posner & Boies, 1971).

Orienting, defined as the overt foveation of a stimulus by movement of the head, eyes, or body (Posner & Petersen, 1990) or the covert (mental) shifting of attention where priority is given to a stimulus (Posner, 1988), allows for more efficient processing of targets in terms of acuity. If a person or a monkey attends to a location, events occurring at that location are responded to more rapidly than if the participant were not attending to the location (Eriksen & Hoffman, 1972; Posner, 1988). Mangoun and Hillyard (1987) found greater EEG activity when participants attended to location, and also stimuli can be perceived at a lower threshold (Bashinski & Bachrach, 1984). These improvements in efficiency can even occur covertly, or before the eyes move (Remington, 1980); this suggests that covert shifts appear to function as a way of guiding the eye to an appropriate spatial area of the visual field (Posner & Cohen, 1984).

Three areas in particular are identified with orienting and aide in the enhancement of efficiency in stimulus processing. Disengaging from a target controlled by the posterior parietal lobe (Mountcastle, 1978; Wurtz et al., 1980) has been shown to be slowed when damage or lesions occur to the area. Similarly, patients with unilateral lesions to the posterior parietal lobe show difficulty disengaging in spatial locations opposite the lesion (Friedrich, Egly, Rafal, & Beck, 1998). Engaging or covert orienting (Petersen, Robinson, & Morris, 1987) is controlled by the lateral pulvinar nucleus of the postereolateral thalamus (Posner, 1988), and the superior colliculus is associated with moving attention from a previous stimulus to subsequent stimuli. Damage in or around the superior colliculus slows attentional shifts and reduces the probability of returning attention to an area already examined in visual search tasks (Posner, 1988; Posner & Cohen, 1984). Petersen, Fox, Miezin, and Raichle (1988) found similar effects in the parietal
cortex using positron emission tomography imaging, confirming the idea that there are
discriminant anatomical areas that carry out specific cognitive operations in relation to
attention.

*Target detection* or discrimination via *selective or focused attention* is a mechanism of
attention that is both a preconscious and conscious feature of attention that includes the selective
biasing of neural function that facilitates the processing of specific information for special
treatment while turning out other signals (Posner & Boies, 1971). Posner and Boies (1971)
separated pre- and conscious selective attention experimentally and concluded that preconscious
attention can be primed by giving information in the form of a warning signal. Preconscious
selective attention is exemplified in the following scenario. Imagine standing on a baseball field
and staring off into the stadium; suddenly someone yells “hey, catch that baseball”. Before you
turn around from the stands to face the field and catch the baseball, selective attention has
already been primed by the warning signal to look for a baseball (Posner 1978). This differs from
the orienting reflex (Sokolov, 1963) in that the warning signal is not specific. For instance, if you
were standing on a baseball field and someone had yelled “look out”, this would not have primed
selective attention, as the warning signal was unspecific. Preconscious attention involves parallel
processing of multiple input codes (Posner, 1978). Conscious selective attention, however,
requires voluntary allocation of attention and selection of an item in a sequential manner (Posner
& Boies, 1971). That is, after the warning signal of “hey, catch that baseball”, you would turn
around, presumably toward home plate and then serially scan the environment in search of the
baseball. Goldman-Rakic (1998) described that there are strong connections between the
posterior parietal lobe and areas of the lateral and medial frontal cortex, and that detecting a
target produces widespread interference with other cognitive operations (Posner, 1978).
Evidence using PET imaging suggests that midline frontal areas such as the anterior cingulate cortex (ACC) and the supplementary motor areas (SMA) are active during word processing (Petersen, Fox, Posner, Mintun, & Raichle, 1988), and blood flow increases in the ACC as the number of targets to be detected increases (Posner, Petersen, & Fox, 1988). Therefore, it appears the ACC is sensitive in operations involved in target detection. People with parietal lesions, when monitoring a stream of auditory information for a sound, were slowed in their ability to orient toward a visual cue (Posner, Inhoff, Friedrich, & Cohen, 1987). The ACC and DLPFC showed increased activity in neuroimaging studies that used Stroop or modified versions of the Stroop task (Bush, Luu, & Posner, 2000; MacDonald, Cohen, Stenger, & Carter, 2000). Together these findings support the notion that there is a distinction between a general alert state and one in which attention is clearly oriented and engaged in processing information.

**Alerting**, also referred to as vigilance, is the ability to prepare and sustain attention to process high priority signals. Posner (1978) experimentally isolated vigilance in a letter word matching study, where participants passively attended to the physical properties of a letter such as its name and semantic classification (vowel). Passively attending to different properties of a letter appears to take place simultaneously regardless if the participants are alert and expecting the target, or they are at a lower level of alertness because the targets occur without warning. An alert state produces more rapid responding at the cost of higher error rates; thus, alertness affects the rate at which attention can respond to a stimulus, such that the selection of response occurs more quickly at high states of alertness. Heilman, Watson, and Valenstein (1985) found that the ability to maintain an alert or vigilant state depends mostly upon the efficiency of the right cerebral hemisphere. People with right hemisphere lesions show signs of neglect, and performance in vigilance tasks is also impaired (Coslett, Bowers, & Heilman, 1987; Wilkins,
Shallice, & McCarthy, 1987). Cohen et al. (1988) found that the midfrontal cortex was most active during an auditory discrimination vigilance task.

The norepinephrine system associated with the locus coeruleus may also play a role in maintaining an alert state. Ashton-Jones, Foote, and Bloom (1984) demonstrated that norepinephrine cells cause changes in arousal or vigilance; similarly, Robinson (1985) reported that rats with right cerebral lesions had depleted norepinephrine. In monkeys norepinephrine innervation is most strongly present in the posterior parietal lobe, pulvinar, and the superior colliculus (Morrison & Foote, 1986), further suggesting that the locus coeruleus is associated with maintaining a vigilant state of attention. Importantly, Posner et al. (1988) found that people with right parietal lesions had slower responses to stimuli in a vigilance task when a warning signal was omitted before a target, while those with left parietal lesions were not affected.

The proposed model of attention (Posner & Petersen, 1990) that demarcates components of attention has attracted a significant response to validate the model. Fan, McCandliss, Sommer, Raz, and Posner (2002) developed the attention network test (ANT) to clearly identify and evaluate the efficiency of alerting orienting and signal detection in a task that is simple enough to obtain data from children, people with attentional defecits, and animals. The ANT is a combination of cued reaction time paradigms (Posner 1980) and flanker tasks (Eriksen & Eriksen, 1974) that assesses the efficiency of the three attentional networks by measuring response times influenced by altering cues, spatial cues, and flankers. Alerting is calculated by subtracting the mean reaction time of a double-cue task, from the mean reaction time of a no-cue reaction task. Neither of these conditions provides information about whether the target will occur above or below the fixation point. Orienting is measured by subtracting mean reaction times from a spatial cue condition from a central cue condition, where both conditions serve as a
form of an orientation cue, but only the spatial cue provides predictive information to allow participants to begin orienting to the appropriate location. Target detection, broadly termed as executive functioning, was found by subtracting mean reaction times of all flanking conditions from the mean reaction time of incongruent flanking conditions.

Vigilance, Focused Attention, and the BCI

To date, BCI research has improved the P300 speller, yet no research has directly focused on attenuating mind wandering, general lapses of attention, or lack of focused attention. Mind wandering in a P300-based BCI task may contribute to user errors. Smallwood and Schooler (2006) operationally define mind wandering as stimulus independent thought (SIT) or thought that diverts from focus in a cognitive task. SIT can be a systematically examinable phenomenon through self-caught mind wandering, where participants are asked to monitor awareness of off-task episodes, or probe-caught mind wandering, where individuals are interrupted during the performance of a task and asked to report experiences. Self-caught mind wandering has been used in an EEG study where mind wandering contributed to the alteration of component structure of the ERP (Cunningham, Scerbo, & Freeman, 2000), and researcher have used probe-caught “zone outs” and text comprehension as a measure of attention (Schooler, Reichle, & Halpern, 2005). Additionally, Teasdale, Lloyd, Proctor, and Baddeley (1995) demonstrated decrements in random number generation during mind wandering; Baddeley (1993) suggested that random number generation requires controlled processing because individuals must refrain from using an automatic response pattern to generate numbers in a random order. Together these data suggest that mind wandering is a diversion from focused attention that may contribute to errors on cognitive tasks, and, in turn, may translate to errors in a BCI.
Alerting may also be compromised by SIT; Smallwood, Obonsawin, and Reid (2003) showed that when sustained vigilance was required in a signal detection task, more errors occurred as the task length increased. This finding also supports the idea that the alerting network is a resource that may be depleted or exhausted (Posner & Petersen, 1990). Birbaumer et al. (1999) reported the first use of a BCI with a paralyzed person, who took a full 16 hours to type a paragraph. A decade later, researchers have improved P300-based BCIs so users can communicate a sentence in about 20 minutes or a total of 10 minutes with the addition of a predictive speller (Ryan et al., 2011). In-home studies on people in later stages of ALS report that BCI use may potentially require hours of sustained and focused attention (Sellers, Vaughan, & Wolpaw, 2010). This evidence supports the fact that a considerable effort to maintain an alert state is required for successful communication on P300-based BCIs.

Moreover, when diverting attention away from the task via distractions or requiring the subject to complete multiple tasks at ones, P300 amplitude is reduced (Kramer, Wickens, & Donchin, 1983; Kramer, Wickens, & Donchin, 1985; Wickens, Kramer, & Donchin, 1984; Wickens, Kramer, Vanasse, & Donchin, 1983). Reductions and distortions of P300 amplitude from overlapping target flashes can contribute to user errors (Martens et al., 2009; Townsend et al., 2010). The effects of distractions on overt selective attention have been shown to provide slower reaction times in Posner cuing tasks (Posner, 1980; Posner, Snyder, & Davidson, 1980). Covert shifts of attention can precede eye movements, directing the eyes to salient information (Hoffman & Subramaniam, 1995). Therefore, both internal (i.e., SIT) and external distractions may contribute to P300 BCI errors, and this converging evidence suggests that BCIs may be dependent on focused attention and vigilance. Implementing mindfulness training may serve to increase state-level attentional focus and reduce internal and external distractions.
CHAPTER 4
MINDFULNESS

Definition of Mindfulness: A Unique Phenomenon

Though many definitions of mindfulness exist, they all converge to suggest that mindfulness is an attentional construct that entails deliberate and receptive attention and vigilance to the present moment (Brown & Ryan, 2003). Mindfulness is both a psychological state of consciousness and a dispositional trait that can vary in the degree to which people are cognizant of their immediate experience (Brown & Ryan, 2003). In both state and trait forms, mindfulness can be situationally induced via therapeutic or meditative means (Kabat-Zinn, 1990, 2003); inducing heightened levels of mindfulness facilitates both enduring increases in trait mindfulness and increases short-term attentional resources (Brown, Ryan, & Creswell, 2007a; Lakey et al., 2011).

According to Brown et al. (2007a) several outgrowths of mindfulness or present-moment attention and awareness exist. One outgrowth of mindfulness is defined as clarity of awareness and has often been described as a "bare" awareness (Engler, 1986, Guntarantana, 2002) that is free from interference by self-related motivations, thoughts, or emotions (Hayes, Strosahl, & Wilson, 1999). Two, mindfulness provides a nonconceptual or nondiscriminatory relationship with the surrounding environment (Marcel, 2003); that is, mindful people are more passive observers of self-relevant thoughts that do not compare, categorize, evaluate, nor ruminate (Brown & Ryan, 2003). Three, mindfulness affords flexibility of attention like a "zoom lens" that moves away from emotions or thoughts to gain a receptive awareness and heightened acuity to the present moment (Brown et al., 2007a). Thus, a person in a mindful state is neither totally indifferent nor unbiased; one can simultaneously be aware of all salient information and mindful
of something in particular. Similarly, Erikson and St. James (1986) provided evidence suggesting that visual-spatial attention could be directed like a “zoom” or “variable-power lens”; mindfulness may be a window through which one is able to control the spatial zoom lens of attention toward target items, particularly on a BCI task.

Four, Brown et al. (2007a) describe mindfulness as an “empirical stance” toward reality that entails present-moment, bottom-up, or nonconceptually-based attentional processing. Similarly, Nyaniponika (1973) suggests that mindfulness is characterized by a deferral of judgment not to be confused with aloofness or disinterest. Five, mindfulness is presently oriented form of attention and awareness (Sheldon & Vansteenkiste, 2005). In accordance with this consequence of mindfulness, traditional clinical approaches such as Rogerian/humanistic (Rogers, 1961) and Gestaltist methods (Perls, 1973) orient clients to the present as a therapeutic means to deter psychological disorders. Finally, mindfulness is continuous, for it varies from rudimentary forms, where mindful moments are fleeting, to a full form, where the mindful state is uninterrupted. Brefczynski-Lewis, Lutz, Schaefer, Levinson, and Davidson (2007) demonstrated that those practicing mindfulness training techniques were more vigilant, relative to controls.

While some researchers (Masicampo & Baumeister, 2007) suggest that mindfulness is too similar to constructs such as self-awareness, self-focused attention and self-control to be considered a distinct construct, Brown and Ryan (2003) and Lakey, Campbell, Brown, and Goodie (2007) argue that mindfulness is indeed a unique phenomenon distinct from self-control. Broadly defined as attentiveness to the self, self-awareness and self-focused attention both concern reflexive consciousness, wherein attention is under the control of self-relevant thought (Brown et al., 2007b). Mindfulness does overlap with these constructs; for example, self-
awareness and mindfulness converge in the key role of heightened attention to subjective experiences. However, these constructs differ in the role of cognition in the operation of conscious awareness, where the mindful person is at a receptive stance on experience, and not a reflexive agent of cognition, and the self-aware person is cognitively reflexive regarding subjective experience. For example, a mindful person’s self-relevant thoughts, images, and identities would be on display in the present moment, whereas the self-aware person would be aware of thoughts but through the frame of self-reflected socially- and culturally-related standards. Empirical evidence suggests that mindfulness and self-awareness differ in regard to private and public self-consciousness. Brown and Ryan (2003) found a null correlation with private self-consciousness and a negative correlation with public self-consciousness ($r = -.02, -.18$, respectively). Similarly, the self-reflexive aspect of private self-consciousness has been linked with a variety of negative health outcomes (Anderson, Bohan, & Barrigan, 1996). While self-awareness and self-focused attention are related to negative health outcomes, mindfulness has been linked to adaptive regulation of emotion (Creswell, Way, Eisenberger, & Liebermann, 2007). Additionally, self-focused attention is associated more with poor mental health and is featured in a variety of forms of psychopathology.

Masicampo and Baumeister (2007) suggest that mindfulness may be as much of a consequence of self-controlled regulation as it is a predictor of self-control, and that mindfulness interventions may represent instances of the exercise of self-control. However, Brown et al. (2007b) argue that mindfulness and self-control branch from two different schools of the self. Mindfulness originates from Buddhist and existentialist traditions explaining the self as a process (Deci & Ryan, 1991), where self-regulation serves attention to momentary experience and the integration of that experience. In contrast, self-control branches from a George Herbert Mead
and Charles Horton Cooley tradition (Ryan, 1993), that views the self as an object that identifies with attitudes, roles, belief systems, and goals that preserve and enhance the self. Self-controlled regulation serves to adhere to socially and culturally derived rules. While outcomes for mindful regulation and self-controlled regulation may be similar, differences have been reported in subjective experience; that is, mindful regulation is vitalizing and energizing (Brown & Ryan, 2003), while self-controlled regulation is energy depleting (Baumeister, Bratslavsky, Moraven, & Tices, 1998). Moreover, in contrast to Masicampo and Baumeister’s (2007) contention that mindfulness training is an exercise of self-control, there is a difference in control efforts of training. Specifically, mindfulness training is not used for seeking conformity to ego-based demands and goal states, the discipline or structure of meditative activity is to provide heightened awareness.

Mindfulness is also understood when it is compared to mindlessness. Though mindlessness is not a direct opposite of mindfulness, mindlessness is typified by a top-down (conceptually-based), self-relevant (Bargh & Chartrand, 1999; Leary, 2005) mode of information-processing. More specifically, a top-down form of attention imposes concepts, labels, and judgments on stimuli encountered in the environment, presumably guided by self-relevant identification with attitudes, goals, or beliefs (Bargh & Chartrand, 1999). Leary (2005) also suggests that cognitive schemas, beliefs, and opinions guide perceptions. This type of information-processing has some adaptive benefit, but quick decision-making can be flawed by automatic assignment of schemas to objects (Barrett, Tugade, & Engle, 2004). Most recently, Farb et al. (2007) found differences in fMRI activity while participants practiced two forms of self-referenced thought; participants in a narrative focus task (nonmeditators) were found to have increased activity in the medial prefrontal cortex (mPFC), supporting the idea that a
conceptually-based mode of self-reference links subjective experiences across time (Gallegher, 2004). Spatially distinct activity was found in people practicing experiential focus or meditation, where reductions in mPFC were observed along with increases in left lateralized regions including the left dorsolateral prefrontal cortex, ventrolateral prefrontal cortex, and posterior parietal cortices; these data support the idea that moment-to-moment experienced self-reference is distinct from conceptual self-reference at a neurological level. Automatic responding is not completely characteristic of mindlessness; For example, when totally involved in an activity like a sport, religious experience, or teaching, Csikszentmihalyi (1975) suggests that flow is a state in which one acts upon internal logic that seems to have no conscious intervention on the individual’s part. That is, mindfulness is not antithetical to mindlessness as defined in flow. Rather, mindfulness is an intentional present-based form of attentional processing (Olendinski, 2005).

Measurement of Mindfulness: Trait and State

Validation of the construct of mindfulness via self-report Likert-scales measures has been one primary focus in recent mindfulness research (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006). Both trait and state mindfulness scales have been developed, tested for reliability and validity, and implemented in clinical, naïve, and meditating populations. Baer et al. (2006) has advocated a multiple-factor self-report measurement of mindfulness to more accurately depict trait mindfulness as a construct that defined by multiple subcomponents. In contrast, several other researchers (Brown, & Ryan, 2003; Chadwick et al., 2008; Feldman, Hayes, Kumar, Greeson, & Laurenceau, 2007; Kumar, Feldman, Hayes, 2005) have developed single-factor trait mindfulness scales, or they have created multiple-factor scales that add the scores of each factor to create a total trait mindfulness score (Buchheld, Grossman, & Walach, 2001). Brown and
Ryan (2003) developed the 15-item Mindfulness Attentional Awareness Scale as a means to identify individual differences in dispositional present moment attention and awareness and reported differences in Zen practitioners and control participants where the practitioners scored higher on the MAAS. This finding indicates that the MAAS is sensitive to individual differences in mindfulness.

Researchers also developed state scales to define mindfulness. For instance, the Toronto Mindfulness Scale (TMS) (Lau et al., 2006) was developed to test the efficacy of mindfulness training programs immediately after training. The TMS contains 15 items that diverge into two factors. The first factor, which is labeled curiosity, reflects awareness of the present moment with a quality of curiosity. For example, “I was curious about my reactions to things”. The second factor, labeled decentereing, emphasizes awareness of one’s experiences with some distance, rather than being carried away by one’s thoughts. Similarly, the MAAS was also altered to tap state mindfulness (Brown & Ryan, 2003), whereby items were framed so that they reflected mindfulness in respect to a task. The present study uses the state MAAS to assess the effects of a 4-week mindfulness training program on state mindfulness.

**Therapeutic Mindfulness Training and Induction**

Although there are several nuances in mindfulness-based therapeutic and induction techniques, they overlap as a means to achieve heightened awareness and attention to the present moment (see Baer, 2003). Currently two therapeutic training regimens exist that solely aim to promote mindfulness. Mindfulness-Based Stress Reduction (MBSR) (Kabat-Zinn, 1982, 1990) is the most cited method, and it was developed in behavioral medicine setting for populations with a wide range of chronic pain and stress disorders. MBSR entails 8 to 10 weeks of weekly meetings that last for 2 to 2.5 hours for instruction and practice of mindfulness meditation skills;
week 6 is usually an 8 hour session that practices body scanning where participants direct attention to numerous areas of the body. The sixth week also includes training in focused breathing, Hatha yoga positions to teach mindfulness of body sensations, and also practices of mindful walking standing and eating (Kabat-Zinn, 1990). Participants of MBSR programs are given “homework” to practice weekly-taught techniques, usually administered via audiotapes or compact disks. Homework typically focuses on a target of observation such as breathing, walking, emotions, or thoughts (Kabat-Zinn, 1990). Mindfulness-Based Cognitive Therapy (MBCT) was introduced by Teasdale, Segal, and Williams (1995) under the presumption that the skills of attentional control taught in mindfulness training could be used to prevent relapse in major depressive disorder by teaching participants to view thoughts nonjudgmentally; this is believed to prevent the escalation of thoughts into ruminative patterns (Teasdale et al., 1995). Segal, Williams, and Teasdale (2002) formalized the first MBCT program to be an 8-week group intervention based on MBSR programs. MBCT incorporates elements of cognitive therapy that foster dethatched or non-self-centered view of one’s thoughts, emotions, and bodily sensations, in which participants will internalize statements such as “thoughts are not facts”.

Some clinical-based interventions incorporate mindfulness into training protocol. Dialectical Behavioral Therapy (DBT) (Linden, 1993a, 1993b) began as a comprehensive approach to the treatment of borderline personality disorder. DBT is based on the assumption that reality consists of opposing forces, and “synthesis” of these forces leads to new realities that in turn have opposing forces. Most central to DBT is that there is a relationship between acceptance and change, whereby clients are encouraged to accept their current state of living at face value, yet also work intensively to change behaviors and environments in order to build a better life (Lineham, 1993a, 1993b). Mindfulness skills are taught within the context of
synthesizing acceptance and change (Baer, 2003). Another therapy that incorporates mindfulness is Acceptance and Commitment Therapy (ACT) (Hayes, Strosahl, & Wilson, 1999). Clients who are enrolled in ACT are taught to recognize themselves as an “observing self” who is capable of watching his or her own bodily sensations. Also, ACT clients are taught to say statements such as “I am having the thought that I am a bad person” rather than saying “I am a bad person”, and are encouraged to experience thoughts and emotions as they arise, without judging evaluation or attempting to change or avoid them. Finally, Relapse Prevention (RP) (Marlatt & Gordon, 1985) is a cognitive behavioral therapy program that is designed to prevent relapses in individuals treated for substance abuse. In RP mindfulness is taught as a technique for coping with urges to engage in substance abuse. For example, RP promotes acceptance of constantly changing experiences of the present moment, whereas addiction typifies the inability to accept the present moment in a persistent seeking of the next high.

While the aforementioned therapeutic techniques foster mindfulness in a receptive state which allows any thoughts, feelings, or sensations to arise while maintaining an attentional stance, concentrative meditation techniques also cultivate mindful awareness. Concentrative meditation techniques include yogic meditation, Buddhist Samatha, focused breathing, and Transcendental Meditation, where participants focus attention to a single stimulus such as a mantra, sound, object, or sensation (Cahn & Polich, 2006). When attention wanders, it is redirected to the object of meditation (Baer, 2003). However, concentrative meditation techniques are dissimilar from mindfulness meditation training, for mindfulness training involves observation of constantly changing internal and external stimuli that is not centered on the focus of one stimulus in particular.
One other means of inducing mindfulness is through teaching participants to consider information or situations from multiple perspectives (Langer, 2002). By teaching people to be mindful of situations, Langer suggests that mindfulness increases creativity and learning. Although Langer (2002) has contributed vastly to the study of mindfulness, her definition focuses solely on perceptual input from external environments, taking a more external perceptual approach to mindfulness. The present study emphasizes mindfulness as openness and unabridged observation of what is occurring not only externally but what is occurring internally as well.

Potential Benefits of Mindfulness to BCIs

Several lines of converging cognitive-behavioral, neurological, and psychophysiological evidence suggest that a 4-week mindfulness meditation training program (MMTP) will improve P300-based BCI performance. Mindfulness researchers have reported several beneficial outcomes of both short-term mindfulness meditation training and long-term meditation practice. Trait mindfulness research suggests that increases in mindfulness as measured by the MAAS are associated with the heightened psychological well-being (Brown & Ryan, 2003). At a general level, mindfulness and meditation heighten attentional awareness (Davidson & Goleman, 1977). Longitudinal studies of focused breathing have shown that children and adults improve performance on the Embedded Figures Test that requires participants to ignore distractions (Kubose, 1976; Linden, 1973). Rani and Rao (1996) also found that children practicing transcendental meditation performed better on the Star Counting Task, supporting that meditation practice leads to improvement on attention-based tasks.

Also noteworthy, Teasdale et al. (2002) suggest that mindfulness or awareness that entails detachment from the self is a variable that is most associated with resistance to depression relapse. As previously explained, Farb et al. (2007) found separate cortical areas underlying
distinct forms of self-reference. In a sample of 20 meditators, MRI brain images point to evidence that long-term meditation increases gray matter (Hölzel et al., 2008). Similarly, voxel-based morphometry data suggest that mindfulness staves off the degradation of gray matter (Pagnoni & Cekic, 2007) perhaps by boosting autoimmune functioning (Davidson et al., 2003). PET scan and fMRI data demonstrate that mindfulness training activates neural systems such as the dorsolateral prefrontal cortex, frontal parietal areas, cingulate cortex, and striatum that facilitate orienting attention and concentration, organization, behavioral regulation, and inhibition, and other executive functioning and attentional control processes (Brefczynski-Lewis et al., 2007; Farb et al., 2007; Jha, Krompinger, & Baime, 2007; Lazar et al., 2000; Lou et al., 1999). Although these studies present mixed findings, this is preliminary evidence to suggest that mindfulness meditation training increases activity in brain areas associated with attention and executive control. Further evidence to support that mindfulness provides more efficient executive control, suggests that mindfulness meditation training alters responsiveness to aversive or stressful situations by decreasing amygdala activation and increasing activation in ventrolateral and ventromedial prefrontal cortical areas (Creswell, Way, Eisenberger, & Lieberman, 2007); these data also support the contention that mindfulness reduces sensitivity to aversive stimuli by promoting a dethatched nonevaluative awareness to the present moment.

Increased Perceptual Sensitivity

Perhaps most important to the use of P300-based BCIs is the increased perceptual sensitivity mindfulness affords. Relative to controls, those who have been taught mindfulness meditation are better able to detect subtle visual differences in the immediate environment (i.e., flashes of light) due to skills in preattentive (less than 200 ms) processing of visual stimuli (Srinivasan & Baijal, 2007). Mindfulness training can even foster abilities to detect subtle visual
targets often not consciously perceived by those untrained in mindfulness because of the attentional blink deficit, which occurs when participants have trouble detecting a stimulus 200-500ms after a prior stimulus (Slagter et al., 2007). Thus, mindfulness serves to shorten the attentional blink deficit and enhance perceptual acuity during the attentional blink. When conscious attention is directed toward a target, those trained in mindfulness are able to sustain attention for a greater period of time because they process information more efficiently than controls (Brefczynski-Lewis et al., 2007; Linden, 1973; Pagnoni & Cekic, 2007; Rani & Rao, 1996). Reduced interference on Stroop tasks, characterized by incongruous color words (e.g., blue, green, red) and colors of the words, is well documented, yet mindfulness training relates to less Stroop disturbance (Chan & Woollacott, 2007).

Jha et al. (2007) made a distinction between two forms of attention termed concentrative and receptive attention, presumably important for BCI control. In the study, three groups of participants (controls, naïve participants who underwent MBSR training, and long-term meditators who entered in a month-long meditation retreat) completed pretest-posttest measures of three distinct but overlapping attentional subsystems (i.e., alerting, orienting, and conflict monitoring; Posner & Peterson, 1990) on the Attentional Network Test (Fan et al., 2002). Concentrative attention is restricted to a specific focus such as breath and is increased in meditation-naïve participants after mindfulness training such as MBSR, whereas receptive attention is characterized as objectless attention that is readied in the present moment of experience without orienting or limiting in any way, and it is increased via long-term meditation practice (Brown, 1977; Delmonte, 1987; Pfeiffer, 1966; Semple, 1999; Valentine & Sweet, 1999). Receptive attention is most closely related to Posner and Petersen’s (1990) alerting component of the attentional network. Jha et al. (2007) found that, indeed, concentrative
attention is improved in early stages of mindfulness training, for naïve participants who underwent MBSR training provided shorter reaction times and were more accurate on the orienting task, and the retreat group showed shorter reaction times and greater accuracy in the conflict monitoring task on a flanker task. This supported the belief that short-term meditation training promotes greater efficiency in the dorsal attention system (orienting and conflict monitoring; Corbetta & Shulman, 2002) Thus, providing short-term mindfulness training may increase concentrative attention, thereby improving BCI performance. Additionally, the retreat group showed shorter reaction times in alerting tasks (response tasks, with no cue) supporting the notion that long-term meditation correlates with greater efficiency in the ventral attention system (alerting; Corbetta & Shulman, 2002).

Event-related potential data have supported that mindfulness and meditation practice increase attention and executive control at both state and trait levels. In a meta-analysis, Cahn and Polich (2006) report several studies that suggest some middle latency components were modulated in a meditation context. Telles and Desairaju (1993) found increases in the Nb component, an auditory-evoked potential, in meditators relative to controls. Also increases in the Na amplitude, generated by early thalamic sensory processes in the midbrain, were found when meditators focused on the mantra om versus the word one (Telles, Nagarathna, Nagendoa, & Desairaju, 1994).

More closely related to P300-based BCI performance, meditation increases P300 response amplitude and decreases latency in both auditory and visual modalities. Cranson, Goddard, and Orme-Johnson (1990) found shorter latency P300 responses at Cz (linked ears reference) in long-term meditators, suggesting that the auditory P300 may reflect trait mindfulness differences. Similarly, Travis and Miskov (1994) found that experienced
transcendental meditators provided decreased P300 latency at Pz (linked mastoid reference) on an auditory oddball task after meditation. Using participants with dysthymia and unaffected control groups, researchers observed increases in P300 amplitude at electrode Cz (linked mastoid reference) for both groups, but most prominently in dysthymic participants (Murthy, Janakiramaiah, & Subbakrishna, 1997). In combination with changes in the auditory P300, P300 amplitude increased and latency decreased in a visual go/no-go task, after a 30-minute meditation period for experienced yogic meditators (Banquet & Lesevre, 1980). Goddard (1989, 1992) found that P300 latency was shorter in meditators than controls in cognitive tasks that increased in difficulty. Much like prior results from auditory tasks, this visually-based P300 latency decrease suggests that trait effects of long-term meditative practice are observed even in increasingly demanding cognitive tasks. More recently, Sarang and Telles (2006) tested the psychophysiological changes of a 3-month cyclic meditation training program. Cyclic meditation is a technique that combines phases of stimulating and calming practices based on statements in ancient yoga texts that suggests combining these states is necessary to reach equilibrium. The study examined P300 latency and amplitude differences in a standard auditory oddball task (ISI 75ms) within-groups; participants either practicing cyclic meditation or supine rest. The greatest differences in P300 amplitude evidenced at electrode Fz. Also, decreased latency and increased amplitudes were found at electrodes Cz and Pz (linked earlobes reference).

Most relevant to this research, Lakey et al. (2011) implemented a 6-minute mindfulness meditation induction (MMI) that had been successfully used to bolster state-level attentional resources by a number of researchers (e.g., Arch & Craske, 2006; Heppner et al. 2008; Jain et al., 2007; McHugh, Simpson, & Reed, 2010). This was the first study that attempted to enhance P300-based BCI performance via mindfulness induction. During the induction researchers
introduced attentional control through concentrative meditation techniques (e.g., focused breathing). Offline analyses of BCI performance showed significantly better performance for participants completing the MMI, relative to controls. Moreover, waveform morphology differences were found at Cz and PO7 (See Figure 7). More specifically, MMI participants provided higher amplitude P300s than controls. Though online data were not reported, Lakey et al. showed that P300-based BCI performance can be improved by inducing state level mindfulness and attentional focus with relatively minimal effort. This study, in concert with the previously presented behavioral, cognitive, psychophysiological, and neurological data, provides preliminary evidence that suggests P300-based BCI performance may be further improved by long-term mindfulness training that may afford more enduring attentional benefits to BCI users.
Figure 7. Offline accuracy was analyzed by taking the grand average of all participants compared between groups to predict averages for every sequence from 1-13 (a sequence is comprised of two target flashes). Mindfulness participants provided greater accuracy and there was less variability in that accuracy as sequences increased. Also, Mindfulness participants provided greater amplitude P300 responses at electrodes Po7 and Cz (modified from Lakey et al., 2010).
CHAPTER 5
THE PRESENT STUDY

I approach the present study with two broad aims. One, I aim to replicate the findings in Townsend et al. (2010) indicating that the checkerboard paradigm (CBP) is a more accurate presentation paradigm than the row column paradigm (RCP). In addition, I aim to extend the findings of Lakey et al. (2010) in several ways. One, examining the effects of a longer, 4-week MMTP training program may provide more robust effects for P300-based BCI performance. Two, comparing MMTP and CTRL performance online will more definitively assess the efficacy of the 4-week mindfulness training program than offline measures. Three, practical bitrate (described below) is assessed along with online bitrate; practical bitrate is a more ecologically valid measure of information transfer rate for it calculates a user’s performance if he or she had corrected errors. Four, a 72-character 8x9 matrix is implemented; larger matrices may be more practically transitioned to in-home settings. Finally, I expand on the findings of Lakey et al. (2010) by optimizing the amount of item flashes presented to the subject during online testing using written symbol rate (WSR; described below). To analyze the effects of mindfulness and stimulus presentation paradigm we conduct this study using a 2x2 mixed-model analysis of variance. Presentation paradigm is a within-subject factor with the levels of RCP and CBP. Mindfulness is a between-subject factor with the levels of MMTP training and a non-MMTP wait-list control group (CTRL). In light of evidence, which strongly suggests that increases in MMTP improve several aspects of attention including cue sensitivity (Jha et al., 2007; Lazar et al., 2000; Lou et al., 1999; Srinivasan & Baijal, 2007; Slagter et al., 2007), distraction inhibition (Chan & Woollacott, 2007), and vigilance (Brefczynski-Lewis et al., 2007; Jha et al., 2007; Lazar et al., 2000; Linden, 1973; Lou et al., 1999; Pagnoni & Cekic, 2007; Rani & Rao, 1996), I hypothesize that MMTP will have important consequences for P300-based BCI users.
Hypothesis 1

In accordance with findings in Townsend et al. (2010) that suggest the newly-developed CBP provides greater accuracy than the standard RCP, I expect a main effect for online accuracy and information transfer rate that shows CBP provides greater online accuracy and faster information transfer rates than the RCP. Also, I expect a main effect for presentation paradigm, such that the CBP provides greater P300 amplitudes and shorter latencies than the RCP. To test these hypothesized main effects, I employed a mixed model factorial analysis of variance (ANOVA) using online accuracy, selections per minute, bit rate, offline predicted selections, and practical bit rate as dependent measures of performance; I also employed these analyses to examine amplitude and latency differences of target responses (i.e., P300 and late negative peak).

Hypothesis 2

Because mindfulness training increases concentrative attention and improves performance on both orienting and conflict monitoring tasks (Jha et al., 2007), I expect a main effect for online accuracy and information transfer rate (practical bit rate) in which MMTP participants provide significantly greater accuracy and information transfer rate than CTRL participants. Similarly, consistent with prior mindfulness and meditation studies that examine changes in the P300 component (auditory and visual; Banquet & Lesevre, 1980; Cranson, Goddard, & Orme-Johnson, 1990; Goddard, 1989, 1992; Lakey et al., 2011; Murthy, Janakiramaiah, & Subbakrishna, 1997; Travis & Miskov, 1994) I expect MMTP participants to provide greater P300 response amplitude and shorter latencies relative to CTRL participants. Mixed model factorial ANOVA was used to test this hypothesis.
Hypothesis 3

I expect an interaction, such that MMTP participants will evidence marked performance improvements and P300 amplitude increases in the RCP, presumably due to the heightened perceptual sensitivity mindfulness affords (Chan & Wollacott, 2007; Jha et al., 2007; Lazar et al., 2000; Lou et al., 1999; Slagter et al., 2007; Srinivasan & Bajal, 2007), and increased attentional demands of the RCP required for optimal performance (Townsend et al., 2010). To test the proposed interaction, I used mixed model factorial ANOVA.
CHAPTER 6

METHODS

Participants

Thirty-six able-bodied subjects participated in exchange for research participation credit. Participants were 23 females and 13 males whose ages ranged from 18-35 years ($M = 22.29$ years, $SD = 3.50$ years). To qualify for the study participants were naïve to BCI use and had normal or corrected-to-normal vision and no known cognitive deficits. The study was approved by the East Tennessee State University Institutional Review Board, and each participant was provided informed consent.

MMTP Training Procedure

The MMTP focused on concentrative meditation techniques by introducing deeper means of attentional control over a period of 4 weeks into the training protocol. Concentrative attention was promoted such that awareness and focused attention to an immediate situation, task, or target occurred without disruption due to external or internal distractions. Inducing state mindfulness represents an extension of the techniques inherent to MBSR (Kabat-Zinn, 1990). In this study participants came in for an initial session, and a research assistant explained the study the concept behind MMTP and then began initial training. Participants returned once-weekly for approximately 1 hour sessions over these 4 weeks. In concert with MBSR training programs, the MMTP implemented a raisin eating task during the first week; in the second week, researchers implemented 15-minute body scanning; walking mindfulness was the focus of training during the third week, where participants would relocate themselves to a small room and focus attention to the sensations of walking; week four employed MBCT training techniques that allowed the participant to detach his or her self from thoughts and emotions and act as “an observer” to such
cognitive processes. Participants completed daily at-home practice using compact discs that employed techniques that were taught during the once-weekly sessions. This at-home practice presumably increased the robustness of the MMTP manipulation. At the final session, immediately prior to completing the BCI task, participants underwent an induction that was previously implemented in a BCI study (Lakey et al., 2011). After hearing task instructions, participants were asked to close their eyes, take a few deep breaths, and turn their attention to their thoughts; as participants’ attention was turned to their thoughts in way that facilitated the observation of the thought, absent from self-reference. The experimenter guided participants through a series of attention manipulations that moved the participant’s attention to the breath, to the abdomen, to the bodily sensations associated with each breath and finally to the computer monitor and the target. Between words, participants were asked to close their eyes and return their attention to their breath for approximately 30 seconds. Thereafter, attention was redirected to the computer monitor and the next target to spell.

Stimuli and Experimental Paradigm

Following provision of informed consent participants were seated in a comfortable chair approximately 1.5 meters from a computer monitor displaying an 8x9 matrix of alphanumerical characters that flashed either the standard RCP (Farwell & Donchin, 1988) or the CBP (Townsend et al., 2010).

Each participant completed one experimental session in which he or she was presented with both the CBP and RCP; conditions were counterbalanced to control for treatment or training effects. Each session consisted of a calibration phase (described below) and an online testing phase for the CBP and RCP. Classification coefficients (described below) were generated with data collected during the calibration phase and subsequently applied during the online test phase.
In each phase participants were provided with target items to which they were requested to focus their attention. In the calibration phase items were displayed at the top of the monitor with the next item to spell indicated in parentheses at the end of the word. The participants were asked to attend to and mentally record the number of times the intended item flashed. For both the CBP and RCP conditions items were flashed for 62.5ms and followed by a 62.5ms inter-stimulus interval. Thus a flash occurred every 125ms (8 flashes/second). For each of the 36 calibration characters, 5 stimulus sequences or 10 flashes of the target item occurred.

Because the P300 has a low-signal to noise ratio, each item was flashed multiple times and the ERP results average (Cohen & Polich, 1997). The number of target items flashed was kept constant during calibration across participants. In both the RCP and CBP a sequence consisted of two flashes of each of the 72 items within the matrix. Each participant was presented five sequences or 10 item flashes per character, and 36 characters selections in the calibration phase. After calibration, SWLDA classification coefficients were cross-validated using written symbol rate (WSR) (Furdea et al., 2009; Townsend et al., 2010). WSR measures how many selections a participant can make in 1 minute. WSR is computed from the number of bits transmitted in a trial (McFarland et al., 2003), where symbol rate (SR) is first determined from the number of bits (B) in a trial, and N is the possible selections to calculate B.

\[
SR = \frac{B}{\log_2 N}
\]

After finding the symbol rate, WSR can be determined through the following equation, where T is the time it takes to make a single item selection.

\[
WSR = \begin{cases} 
\frac{2SR - 1}{T} & SR > 0.5 \\
0 & SR \leq 0.5 
\end{cases}
\]
This metric was used to optimize the amount of flashes presented to each participant, where the amount of flashes that corresponded to the highest WSR was used to maximize online performance. For instance, some participants saw a maximum of 10 item flashes for each target, whereas others could see as few as 3 flashes. This metric provides an ecologically valid representation of communication rate because WSR assumes error correction. When a participant corrects an error, he or she requires two subsequent selections to correct the error: a backspace to delete and then a correct selection of the intended character. From a practical standpoint, a symbol rate that is less than 0.5, indicates that the user makes more errors than he or she is able to correct.

**Data Acquisition**

Thirty-two channels of EEG were recorded from a standard tin electrode cap (Electro-Cap International, Inc.) All channels were referenced to the right mastoid and grounded to the left mastoid. Prior to stimulus presentation, the experimenter reduced electrode impedances to below 10.0 kΩ. Two g.tec (Guger Technologies) 16-channel biosignal amplifiers were used. The amplifiers have a +/-250mV input sensitivity and are amplified to +/-2V before the ADC converts the signals to digital format. Signals were sampled at a rate of 256 Hz, and high-pass filtered at 0.5 Hz, and low-pass filtered at 30Hz. Though 32 channels were collected for possibility of future analysis, only electrodes Fz, Cz, P3, Pz, P4, PO7, PO8, and Oz (Sharbrough, Lesser, Lüders, Nuwer, & Picton, 1991) were used for BCI operation (Krusienski et al., 2008). BCI 2000 controlled stimulus presentation, data collection and online processing (Schalk, McFarland, Hinterberger, Birbaumer, & Wolpaw, 2004).
Classification

In the present study independent SWLDA classifiers (Draper & Smith, 1981) were derived for the RCP and the CBP. RCP calibration included the data from 3,060 items (360 targets and 2,700 nontargets). Eighty-five total intensifications (10 targets and 75 nontargets) were used for each of the 36 calibration characters in the RCP. The CBP requires more flashes (24) to complete a sequence than the RCP (17); thus the CBP calibration included data from 4,320 items (360 targets and 3,960 nontargets). One hundred twenty total intensifications (10 targets and 110 nontargets) were used for each of the 36 calibration characters in the CBP. SWLDA is a linear regression procedure that determines the best features that distinguish the difference between target and nontarget stimuli. Implemented in MATLAB (version 7.6 R2008a, stepwisefit function), SWLDA performs a forward regression procedures by selecting the feature that accounts for the most variance and a second feature that accounts for the most remaining variance. This two-feature model is then tested in a backward regression. This procedure continued by adding a third feature to the model until no additional features reached criteria for entry ($p < .10$) or removal ($p > .15$) from the model. A maximum of 60 features were allowed in the model. These features were presented in a set of spatiotemporal classification coefficients that were weighted.

Online classification was performed by averaging all 800 ms poststimulus epochs for each character. For example, if a participant required three flashes in the CBP a total of 36 epochs would be averaged (3 targets and 33 nontargets). In the RCP the features were applied to the averaged online epochs and the feature weights were summed for each row and column. The letter, number, or computer command located at the intersection of the row and column containing the highest score was presented to the participant in feedback. Similarly, in the CBP
features were applied to the averaged online epochs; the character with the highest score was presented to the participant as feedback.

**Computation of Dependent Measures**

Performance-based measures included online accuracy, selections per minute (traditional, theoretical, and practical), offline practical selections, and bit rate (traditional, theoretical, and practical). *Online accuracy* was measured by taking the number of correct selections during the online testing phase and dividing this value by the total number of selections per session (36 items). *Selections per minute* was calculated by taking the total number of selections and dividing these selections by the total time of the session. A formula first described by Pierce (1980) was used to calculate *bitrate*. The formula incorporated the number of possible targets (*N*) and the probability that the target was accurately classified (*P*):

\[
\text{Bit Rate} = \log_2 N + P + (1-P) \log_2 \left( \frac{1-P}{N-1} \right).
\]

The result was divided by the number of minutes in a session to yield *bits per minute*.

In a practical sense, users need to correct errors, and correcting errors requires a minimum of two selections, one selection to backspace and a second correct selection of an error. Sellers et al. (2006) conducted a simulation on 10,000 item selections, examining the amount of selections it would take a participant to select 10 items, given accuracy of 50%-100%. Fifty-one percent accuracy required 500 selections necessary to complete 10 items. Although, bit rate is an objective measure, the importance of accuracy should not be overlooked. Researchers developed a formula that adds two selections for every error made by the participant as a more ecologically valid measure of bit rate (*error-corrected or practical bit rate*). Assuming that the probability of making an error is “p” and the participant is attempting to communicate “N”
correct selections, the total number of selections required to achieve success is given by the infinite series:

\[ N + 2(N)p + 2(2(N)p)p + 2(2(2(N)p)p)p + \cdots = N \sum_{i=0}^{\infty} (2p)i \]

This series converges to \( \frac{N}{1-2p} \) provided that \( 2p < 1 \), which holds whenever \( p < 0.5 \). Using this formula, I determined offline practical selections, or the expected number of total selections required by each participant in order to successfully complete all 36 selections. These offline practical selections were divided by the predicted time to complete the session to create practical selections per minute, and then added to the bitrate equation to compute practical bitrate.

Theoretical selections per minute and bitrate was calculated by subtracting the time (2 seconds) between sequences and using that time so that the total number of selections was divided by the theoretical time. Thereafter, theoretical selections per minute was used to calculate bitrate.

Waveforms were created by averaging each participant’s target responses within the 800ms recording epoch for each condition. Because these waveforms were expected to reflect the performance differences, classification electrodes (Fz, Cz, P3, Pz, P4, PO7, PO8, & Oz) were averaged. Windows were set for the positive peak between 175ms and 312ms. The late negative peak was set between 332ms and 617ms. Thereafter, peak latencies and amplitudes were extracted for each subject, averaged, and compared across conditions.
CHAPTER 7

RESULTS

A 2 x 2 x 2 mixed model factorial analysis of variance—Order (CBP first or RCP first) x Attentional Manipulation (MMTP or CTRL) x Paradigm (CBP and RCP)—was used to examine if an order effect was present in these data. For each dependent measure the results provided insufficient evidence to reject the null hypothesis. Thus, I collapsed across the conditions and used a 2 x 2 mixed model factorial analysis of variance to examine differences and interactions between Attentional Manipulation (MMTP and CTRL) and within Paradigm (CBP and RCP) conditions on the measure of online accuracy, selections per minute, bitrate, offline practical selections, practical bitrate, and waveform latency and amplitude.

A preliminary mindfulness Manipulation check was conducted to compliment the BCI accuracy results and test the efficacy of the 4-week MMTP. A six-item mindfulness questionnaire assessed attention to and awareness of the present moment using responses to a five-point Likert Scale. This scale was derived from a portion of the 15-item Mindfulness Attentional Awareness Scale (Brown & Ryan, 2003) that was altered to reflect state mindfulness. All items were summed such that participants could report a score as low as 6 or as high as 30. Participants who underwent MMTP reported greater scores on the questionnaire ($M = 25.52, SE = .74$) than CTRL participants ($M = 23.31, SE = .75$), $t(34) = 2.09, p = .04, d = .72$.

P300 Speller Performance

Most importantly, statistically significant main effects emerged for both Attentional Manipulation and Paradigm for online accuracy (See Figure 8). Overall, MMTP participants provided greater online accuracy ($M = 88.62\%, SE = 2.42\%$) than controls ($M = 79.79\%, SE = 2.29\%$), $F(1,34) = 7.03, p = .01, \eta^2 = .17$ and accuracy improved when participants were presented
the CBP ($M = 86.78\%, SE = 2.09\%$) compared to the RCP ($M = 81.14\%, SE = 1.63\%$), $F(1,34) = 10.37, p < .01$, $\eta^2 = .23$. No interaction was found for online accuracy $F(1,34) = 2.34, p = .14$, $\eta^2 = .06$.

Figure 8. Online accuracy was analyzed by taking the average accuracy of all participants and comparing them with a mixed-model ANOVA. A main effect emerged for the Attentional Manipulation such that MMTP provided greater accuracies than CTRL participants. Similarly, the CBP outperformed the RCP.

Similarly, main effects were reported for both Attentional Manipulation and Paradigm for offline practical selections (OPS) (See Figure 9). OPS provides an accurate metric for the predicted amount of selections to successfully complete the 36 selections in the session. MMTP participants required fewer selections ($M = 48.26, SE = 2.62$) than CTRL participants to complete the session ($M = 57.87, SE = 2.49$), $F(1,34) = 7.09, p = .01$, $\eta^2 = .17$. The CBP paradigm allowed for fewer offline practical selections ($M = 50.33, SE = 1.75$) than the RCP paradigm ($M$
No interaction was found for offline practical selections $F(1,34) = 2.39, p = .13, \eta^2 = .07$.
Figure 10. A) Depicts online selections per minute. For online selections per minute, there was a significant main effect such that the RCP afforded more sel/min than CBP. B) After removing time between selections (2 seconds), the theoretical sel/min did not provide significant main effects or an interaction. C) While online and theoretical sel/min represent optimistic measures, practical sel/min is a more ecologically valid measure. MMTP participants provided seemingly higher practical bitrates; however, these differences were not significant.

Similarly, no main effects or interactions were found for bitrate, theoretical bitrate, or practical bitrate (bit/min) (See Figure 11). Figure 11 indicates that while MMTP provided high practical
bitrates ($M = 21.32$ bit/min, $SE = 2.67$ bit/min) as compared to CTRL ($M = 16.78$ bit/min, $SE = 2.52$ bit/min), these differences were not statistically significant $F(1,34) = 1.53, p = .22, \eta^2 = .04$.

Subjective preferences support that a majority of participants preferred the CBP over the RCP (88.9% or 32 of 36). Qualitative self-reports were assessed, and participants who preferred

![Figure 11](image-url)
the CBP cited that the system was easier to use than the RCP, for “there was less distracting characters around the letter”, “much easier to zone in on the letter”, and “the time between the flash was much longer”. In contrast, one of the three participants who preferred the RCP stated that “it was not as strenuous and the RCP was shorter” in the time it took to complete a sequence as compared to the CBP. However, all three participants who preferred the RCP were in the CTRL condition and completed the RCP first; thus, these participants preferences may be driven by their fatigue in the later part of the session.

Waveform Morphologies

As indicated in Figure 12, no interactions were found for amplitude and latency for either the positive or negative peak. MMTP participants provided higher average positive peak amplitudes ($M = 3.43\mu V$, $SE = .33\mu V$) than CTRL participants ($M = 2.63\mu V$, $SE = .43\mu V$), but these differences were not statistically significant $F(1,34) = 2.69, p = .11$. Main effects were observed for paradigm. The CBP provided significantly greater positive peak amplitudes ($M = 3.31\mu V$, $SE = .31\mu V$) relative to RCP ($M = 2.88\mu V$, $SE = .29\mu V$), $F(1,34) = 7.44, p = .01$. CBP also provided greater amplitude late negative peaks ($M = 2.91\mu V$, $SE = .22\mu V$) than the RCP ($2.47\mu V$, $SE = .18\mu V$), $F(1,34) = 10.21, p < .01$. Figure 12 also shows that there was a main effect for the late negative peak latency such that CBP had a shorter latency ($M = 462ms$, $SE = 9ms$) than RCP ($M = 492ms$, $SE = 15ms$) $F(1,34) = 12.97, p < .01$. 
Figure 12. A) Individuals’ peak amplitudes and latencies were averaged by condition and analyzed via 2 x 2 mixed-model factorial ANOVA. The eight classification electrodes were averaged and then positive peak amplitudes and latencies were extracted within the 175ms-312ms, (window in orange). Similarly, late negative peak amplitudes and latencies were selected between 332ms-617ms. B) Several main effects emerged for paradigm suggesting that both the P300 and late negative peak evidenced greater amplitudes and shorter latencies. No differences were observed for the MMTP manipulation, but it is likely that there was insufficient statistical power to reject the null hypothesis.
CHAPTER 8

DISCUSSION

Previous research suggests that using P300-based brain-computer interfaces requires a considerable amount of time and necessitates sustained focused attention (Birbaumer et al., 1999; Ryan et al., 2011; Sellers, Vaughan, & Wolpaw, 2010). Problems such as general lapses of attention and mind wandering can undermine performance on cognitive tasks (e.g., Smallwood & Schooler, 2006) and may similarly reduce the online accuracy of the P300 speller. With this in mind, I examined the possibility that a 4-week mindfulness meditation training program could mitigate attentional lapses and improve online accuracy for the P300 speller. A secondary aim of this study was to systematically replicate the findings in Townsend et al. (2010) that suggest that the newly-developed CBP outperforms the standard RCP (Farwell & Donchin, 1988). At the within-subjects level I found that the CBP, indeed, provided greater online accuracy and required fewer predicted selections to successfully spell all 36 online characters relative to the RCP. However, the RCP still evidenced greater selections per minute than the CBP. Most importantly, MMTP provided significantly greater online accuracy, and required fewer predicted selections than CTRL participants. Main effects also emerged in the waveforms for both paradigm and attentional manipulations. CBP provided significantly greater positive peak amplitudes relative to the RCP. The CBP also evidenced greater amplitude late negative peaks, and shorter latencies. The attentional manipulation did not provide waveform differences. I expand on the importance of these findings below.

Even though the RCP is a rather accurate paradigm that yields strong performance on the P300 speller task, recent advances in paradigms (i.e., CBP) surpass the RCP. Hypothesis 1 suggested that in concert with the findings in Townsend et al. (2010) the CBP will show greater
online accuracy than the RCP; the CBP was also expected to provide greater amplitudes and shorter latencies for target responses. The findings in this study support the hypothesis and successfully replicate the findings of Townsend et al. (2010). Similarly, the CBP requires significantly fewer selections to successfully complete a series of characters. While the previously reported findings support hypothesis 1, a main effect emerged such that the RCP allowed more selections per minute than the CBP. It may seem that, in light of this finding, the RCP affords quicker spelling than the CBP regardless of errors. However, this metric for selections per minute is more optimistic than when controlling for errors. That is, no differences were found when errors were taken into account; although practical bitrate and practical selections per minute are offline measures, each provides a more ecologically valid, or a more realistic, metric of information transfer rate.

Combined with these performance increases, target responses—or positive and late negative peaks—were of greater amplitude and shorter latency for the CBP. The CBP’s removal of flanking items and double-flashes may contribute to these waveform differences and provide an avenue for explaining as to why the CBP outperforms the RCP. Indeed, researchers have shown that in a standard flanker task, response times increase when nearby items belong to a class that is different from the target class (Sanders & Lamers, 2002). For instance, when adjacency errors occur in the RCP, one of four flanking items that are immediately adjacent to the target is selected. The CBP’s shorter response latencies may be a direct cognitive psychophysiological marker of faster stimulus evaluation. Stated differently, without adjacent-flashing items, the CBP requires less interference from the flanking items that distract users in the RCP. Moreover, amplitude increases may be explained by the elimination of double flashes. When two targets overlap temporally, P300 amplitude may be reduced or the entire waveform
morphology may be changed (Martens et al., 2009; Waldorff, 1993). Collectively, these greater amplitude and shorter latency responses are psychophysiological evidence that the CBP affords less distraction and that the CBP provides a more accurate platform for the P300 speller. Importantly, Townsend et al. (2010) found that ALS users performed better with the CBP than the RCP. Thus, the translational applicability of the CBP may yield greater online performance for disabled users.

Hypothesis 2 suggested that mindfulness would increase users’ accuracy online and provide target responses of greater amplitude and shorter latency, presumably due to greater acuity or attenuated distraction. The findings of this study are in support of hypothesis 2, for MMTP participants evidenced significantly greater accuracy on both presentation paradigms relative to CTRL participants. Additionally, offline analyses predict that fewer selections were needed to successfully complete a series of characters. These findings support the contention that long-term mindfulness training may increase concentrative attentional resources (e.g., Jha et al. 2007). These increases seem to be facilitated by attunement or heightened perceptual sensitivity to target stimuli on the BCI task; however, it is important to note that these better accuracies could, in part, be helped by decreases in internal and external distractions.

Currently, it is unclear whether the performance increases are attributable to increases in attentional focus or to decreases in distractibility. For instance, previous neurological research has demonstrated that mindfulness increases attentional focus (Brefczynski-Lewis et al., 2007; Jha et al., 2007; Lazar et al., 2000; Lou et al., 1999; Linden, 1973; Pagnoni & Cekic, 2007; Rani & Rao, 1996) and perceptual sensitivity (Banquet & Lesevre, 1980; Cranson, Goddard, & Orme-Johnson, 1990; Goddard, 1989, 1992; Lakey et al., 2011; Murthy, Janakiramaiah, & Subbakrishna, 1997; Travis & Miskov, 1994). Similarly, there is evidence to support that
mindfulness inhibits mind wandering and inhibits the extent to which irrelevant stimuli—such as nontarget flashes on a P300 BCI—lead to distraction (Chan & Woollacott, 2007; Slagter et al., 2007; Srinivasan & Bajal, 2007). Future research should aim to explore the extent to which increased focus and decreased distractibility mediate these performance increases. It may be possible to examine internal distractions systematically via self-caught or probe-caught stimulus independent thought paradigms.

As noted by Lakey et al. (2011) these findings may also be attributable to a number of different psychophysiological processes that underlie or influence attentional systems either directly (e.g., Brefczynski-Lewis et al., 2007; Jha et al., 2007) or indirectly. For instance, one of the benefits to mindfulness is that it reduces negative affect by decreasing amygdala response to aversive stimuli (Creswell et al., 2007), and in turn, mindfulness can decrease the production of cortisol (Way, Creswell, & Eisenberger, 2010). Another potential benefit of mindfulness is that it may indirectly produce reduction in heart rate a marker of physiological relaxation (Davidson et al., 2003; Ditto, Eclache, & Goldman, 2006). Lakey et al. (2011) emphasize that mindfulness is not completely explained if it is defined as physiological relaxation, for mindfulness also entails heightened awareness of and attention to the present experience. Empirical evidence supports the fact that mindfulness is distinct from relaxation (e.g., Lazar et al., 2000; Jain et al., 2010). Thus, to the extent that mindfulness increases attentional resources, it also possible that attention is indirectly increased by attenuating negative affect and promoting relaxation.

While it was hypothesized that the classification electrodes would evidence greater amplitude and shorter latency target responses as a means to explain why these performance increases occurred for MMTP participants, no main effects for the attentional manipulation were observed. Based on the data, it appears that statistical power likely was insufficient to reject the
null hypothesis. More specifically, there was a trend such that MMTP participants were almost a full microvolt higher than CTRL participants, but these differences were not statistically significant. This may be due to the increased variability in CTRL participants’ target responses. The standard error of the control group was higher than the MMTP group; target response amplitudes were more consistent for MMTP participants. Similarly, Lakey et al. (2011) reported that participants who had undergone a short mindfulness induction responded to targets more reliably (i.e., consistently) than controls across the experimental trials. It is still unclear as to whether this consistency is manifested in waveform morphology. Perhaps mindfulness training provides more consistent target responses within-subject by increasing vigilance or concentrative attention or reducing internal and external distractions. While greater amplitude P300 responses are a hallmark of better SWLDA classification, consistency of the response may contribute to successful SWLDA classification and bolster online accuracy.

I also hypothesized that there would be an interaction such that mindfulness would significantly increase user performance on the RCP relative to controls. These data do not support hypothesis 3, but again it is possible that the statistical power was insufficient to reject the null hypothesis. Decomposing the interaction to examine simple effects was promising in that it showed performance differences for the RCP. The simple effects suggest that MMTP participants have greater online accuracies and require fewer predicted selections than CTRL participants while spelling with the RCP. Furthermore, similar waveform differences were found at electrodes PO8 and Oz; these amplitude differences support hypothesis 3 for they reveal that MMTP participants evidenced greater amplitude target responses at the positive peak than CTRL participants. Although it is difficult to make inferences from these findings, with the addition of more participants, these data are promising preliminary evidence to support hypothesis 3. Stated
differently, MMTP may buffer internal and external distractions related to the RCP, or it could be equally possible that the heightened attentional resources the MMTP affords accounts for greater online accuracy than CTRL participants.

Perhaps most importantly, we found that participants who have undergone MMTP provide significantly greater online accuracy than CTRL participants. It is possible that mindfulness training may be implemented in a clinical setting for BCI users who have been diagnosed with severe neuromuscular disorders. Reductions in negative affect and decreases in the amount of time it takes to complete a desired message (i.e., fewer predicted selections per minute may reduce user frustration. Moreover, target response waveform morphologies cohere with previous findings in Lakey et al. (2011). More broadly, by extending the findings of Lakey et al. (2011) with online accuracy, practical bitrate, larger 72-character matrices, and optimizing sets per sequence, the present study highlights the fact that MMTP may bolster participants’ performance by promoting user focus on target items or inhibiting user distraction.

Limitations and Future Directions

Though MMTP improved P300-based BCI performance, there are a number of limitations to my conclusions that should be addressed in future research. For instance, shorter P300 latencies were not observed for MMTP participants; however, this study used a 4-week MMTP that aimed to bolster concentrative attention. Jha et al. (2007) reported that long-term meditation practitioners responded more quickly on Posner alerting tasks wherein participants were required to respond to a stimulus when they were not provided a cue and were unaware of the location of the target stimulus. Long-term meditation is believed to increase ventral attentional networks associated with receptive attention—attention that does not pertain to an object, but a general readiness to respond. Thus, shortened latencies may be a product of
heightened receptive attention that is a characteristic of higher levels of dispositional mindfulness. The MMTP in the present study is in line with MBSR/MBCT programs in that it serves to increase dorsal attentional mechanisms associated with concentrative attention—attention that is contingent on an object, such as orienting or conflict monitoring (Jha et al., 2007). Future researchers should be cognizant of this fact, and it will be useful to test P300-based BCI performance with long-term meditation practitioners.

With these data, it is difficult to draw any conclusions about the long-term benefits of mindfulness beyond the completion of the P300 speller task. However, researchers have noted that therapeutically, mindfulness training affords enduring increases in trait mindfulness (Brown & Ryan, 2003). Thus, it is likely that long-term mindfulness training would offer attentional benefits beyond the P300 speller task. Future research should implement follow-up testing to capitalize on and confirm the enduring trait effects of mindfulness training. Because able-bodied participants were used in this study, I am limited to drawing conclusions about how MMTP may improve BCI use among individuals with severe neuromuscular disorders. Despite this fact, the present study uses a BCI system design and set-up similar to one that has been used in an extensive in-home study with a person who has ALS (see Sellers, et al., 2010). Future research should test the efficacy of MMTP on a clinical population. Lakey et al. (2011) noted that people with severe neuromuscular disorders may benefit from mindfulness training outside of P300 BCI use, for previous research demonstrates that mindfulness increases (Hölzel et al., 2008) or at least staves off the degradation of grey matter (Pagnoni & Cekic, 2007). Additionally, mindfulness is positively related to psychological well-being and positive affect and negatively related to several poor psychological and physical health outcomes (Brown & Ryan, 2003). BCI researchers must be cognizant of factors that foster psychological well-being and good physical...
health. Accordingly, researching the effects of longitudinal MMTP may provide benefits outside of improved P300 BCI performance for people with neurodegenerative diseases like ALS.

Using EEG data, it is difficult to draw firm conclusions about underlying neuronal generators of ventral and dorsal attentional mechanisms that are presumably altered by mindfulness training. According to Tenke et al. (1993) the component structure of an ERP is conceived as the electrophysiological correlate of underlying neuronal activity that is task dependent and manifests a specific time course and topography. In the present study, I examined target response differences on the classification electrodes to explore why accuracy differences occurred. These performance-related responses use a right mastoid reference from which all electrodes are subtracted. This referencing scheme attenuates responses closer to the reference electrode and may alter responses so that they do not accurately reflect the neuronal activity. Moreover, for the purpose of comparing waveforms in respect to performance, I retained eye blinks and muscle artifacts in the data. In an effort to further validate the construct of mindfulness and potentially extend previous findings that suggest mindfulness training improves the efficiency of anterior (conflict monitoring and alerting) and posterior (orienting) attentional networks (Jha et al., 2007), future research should aim to examine the topography and time course of the ERP component structure by removing artifacts and testing different referencing schemes such as a common average reference or surface laplacian (two-deminsional Current Source Density; Tenke & Kayser, 2005). Collectively, these next steps, as mentioned in the present section, will allow researchers to understand better the effects of MMTP on underlying attentional networks—further validating the construct mindfulness at a theoretical level. Additionally, these steps will help to maximize the practical benefits of MMTP for BCIs.
Conclusions

Brain-computer interfaces provide communication and control that is independent from muscular outputs. MMTP affords a nonmedicinal means to increase concentrative attention at a state level and improve P300-based BCI performance, particularly for the RCP. Consistent with Townsend et al. (2010), the CBP provides significantly better performance than the RCP, and may still yield the best online P300 speller performance to date. The next logical step is to replicate these findings and test the efficacy of MMTP on much larger group of people with ALS or other severe neuromuscular disorders.
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