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The Behavioral and Electrophysiological Effects of Discrimination and Inhibition Training on Visual Selective Attention: an ERP and Time-Frequency Analysis

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The Behavioral and Electrophysiological Effects of Discrimination and Inhibition Training on

Visual Selective Attention: an ERP and Time-Frequency Analysis

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Abstract

Enhancement of task relevant information and the suppression of task irrelevant information are the two co-occurring mechanisms of selective attention. Studies have shown that ERP components (specifically N2, P3, and RP) and the alpha band (8-14 Hz) rhythm correspond to neural mechanisms and processes of visual selective attention, especially conflict resolution. Tested by a modified version of the visual flanker task, a conflict task employing inhibitory control, two groups of healthy adults were exposed to three weeks of cognitive training; either discrimination training (trained to discriminate target orientation) or inhibition training (trained to ignore interfering distractors) to investigate whether training impacts behavioral and neural correlates associated with stimuli processing. Behavioral analysis revealed a reduction in both Garner interference [$F(1,33)=6.85$, $p=0.01$] and Congruity effect [$F(2,66)= 4.35$, $p=.02$] after inhibition training, indicating better conflict resolution. Neural analyses revealed that the amplitude of N2 to target stimuli increased equally for both congruent and incongruent trials, albeit to a larger degree after inhibition training compared to discrimination training [$F(1,32)= 5.18$, $p<.05$]. Meanwhile, inhibition training decreased the magnitude of P3 [$F(1,32)= 5.69$, $p<.05$] and increased the magnitude of Rejection Positivity (RP) [$F(1,32)= 4.87$, $p<.05$] to incongruent distractors. As the magnitude of RP increased, behavioral performance (RT and accuracy) improved across both training groups. As the first alpha-band training study, we found non-group specific training effects which did not vary as a function of either discrimination training or inhibition training. Hence, we suggest that the alpha band may not be amenable to inhibitory control training employing a conflict task. Instead, the training effects are specific to the ERP waveforms: N2, P3, and RP.

The Behavioral and Electrophysiological Effects of Discrimination and Inhibition Training

on Visual Selective Attention: an ERP and Time-Frequency Analysis

One of the most fundamental executive functions in humans is our use of attention to prioritize information, which lays the groundwork for all our understanding, learning, and innovating. It is understood that attention is a cognitive resource that is limited in the amount available to allocate, making it imperative that one uses the limited attention available appropriately and optimally. Being constantly surrounded by numerous stimuli begging for one's attention, individuals must be able to filter the relevant information from the irrelevant information (Lavie, Hirst, de Fockert, & Viding, 2004). An individual's ability to focus on relevant information (e.g. targets) presented in the environment, while ignoring the irrelevant information (e.g. distractors), is defined as selective attention (Melara, Rao, & Tong, 2002; Paczynski, Burton, & Jha, 2015; Feldmann-Wüstefeld, Uengoer, & Schubö, 2015; Schneider, 2017; Moore & Zirnsak, 2017). How the relevant information is selected and filtered from the abundance of stimuli in the environment in the process of selective attention has been heavily debated and researched over the years.

In the recent years, researchers have strived to train participants in selective attention capabilities by trying to improve components of selective attention such as inhibitory control (Melara et al., 2002; Thorell et al., 2009; Berkman et al., 2014) or conflict resolution (Rueda et al., 2005; Millner et al., 2012). The efficient use of these components of selective attention is integral for an individual to make optimal use of their limited capacity. Contrary to the traditional view of selective attention which focuses on target processing, these components of selective attention pertain to the processing of distracting and interfering information as an individual allocates his or her attention to the task at hand. Hence, training individuals to

improve their attentional control by suppressing distractors using inhibitory control and conflict resolution is the next step in increasing our understanding of the mechanisms of selective attention. Moreover, the current study extended previous research on selective attention by demonstrating that inhibitory control is amenable to training in the visual modality and is associated with improved attentional capabilities under conflict and non-conflict situations.

Traditional Theories of Selective Attention

The traditional theories of selective attention, proposed by Broadbent (1958), Deutsch and Deutsch (1963), and Treisman (1964), characterized selective attention mechanisms as corresponding primarily to the activation of target processing. Theories of selective attention sought to understand how perceived information is selected and processed. Broadbent (1958) proposed that because it is impossible for all incoming stimuli to be processed, attention is limited in capacity, hence, a "bottleneck" filter must be in place that limits the flow of information from the environment. The bottleneck model postulates that salient information is filtered through to consciousness whereas the rest of the information is withheld from processing. How the salient information is detected, filtered, and processed was addressed by Broadbent (1958). He conducted an experiment using a dichotic listening task in which participants heard two differing messages in either ear; participants were instructed to repeat the messages heard in one ear (e.g. attended stimuli) while ignoring the messages from the other ear (unattended stimuli), a task called shadowing. Broadbent found that participants were able to successfully repeat the attended messages without excessive interference from the unattended messages. Broadbent (1958) proposed his Filter theory (now called the Early Selection Theory of Attention), which stated that all incoming stimuli enter through a sensory buffer from which the relevant information is filtered out from the irrelevant information, based primarily on the

physical characteristics of the stimuli. In this account, only relevant information is filtered

through and processed for meaning, whereas other irrelevant information is filtered out and lost.

Although the theory captures many everyday examples of selective attention, phenomena such as

the cocktail party effect cannot be explained using this theory. The cocktail party effect occurs

when an individual is able to hear his or her own name even when engaged in another task or

conversation, suggesting that unattended information is not filtered out completely or lost from

processing (Cherry, 1953).

Addressing this discrepancy, researchers Deutsch and Deutsch (1963) proposed an

alternative model from the Filter theory which stated that all incoming information is processed

for meaning prior to the filtering out of the irrelevant information (now called the Late Selection

Theory of Attention). This model suggests that all stimuli registered by the senses is defined for

meaning subconsciously from which the unattended information is filtered out and the attended

information reaches conscious awareness for full processing. Therefore, any pertinent

information embedded in the unattended channel is perceived because the unattended stimuli are

processed for meaning, thus explaining the cocktail party phenomenon. To Treisman (1964),

who agreed with Broadbent (1958) in early selection, the processing for meaning of all incoming

stimuli appeared to be a wasteful use of cognitive resources, hence he suggested the attenuation

of unattended information rather than the complete filtering out prior to semantic processing.

Treisman (1964) proposed that all the relevant incoming information reaches semantic

processing while the irrelevant information is attenuated, reduced in intensity, such that it is not

completely processed, yet it is not fully ignored either. Treisman (1964) reproduced Broadbent's

(1958) experiment using a dichotic listening task and a shadowing method to show that

unattended messages are not completely ignored because if the unattended stream contains

relevant information (e.g. the participant's name), they will be processed. Treisman's theory

(now termed the Attenuation Theory of Attention) addresses both the Early and Late Selection

Theories and suggests an intermediate position for the mechanism of selective attention in which

the attended information is fully processed for meaning, whereas the unattended information is

passively processed because the "attenuator" reduces the intensity of the unattended incoming

stimuli, but does not inhibit processing completely. This process allows us to pay attention to

relevant information in our environment while being passively aware of other unattended stimuli.

Behavioral Tasks

These traditional views of selective attention were focused on target selection and

processing. Over the years, researchers have developed various tasks to measure target

processing in selective attention. The behavioral data acquired from these tasks has allowed

researchers to propose possible underlying mechanisms that contribute to the cognitive

functioning of selective attention. Behavioral performance in these tasks, including reaction

times (RTs) and accuracies/errors rates, was analyzed to explore attention and target processing.

Selective attention performance can be gauged in either stimulus effects or task effects. Stimuli-

specific effects measure differences in performance as a function of stimulus congruity.

Congruity is the compatibility between features of the target(s) and distractor(s). Congruent trials

involve matching targets and distractors. For example, if the target is the color red and the

distractor is the word "RED", they are congruent in meaning. Incongruent trials, on the other

hand, involve mismatching features between target(s) and distractor(s) (e.g. target is the color red

and distractor is the word "GREEN"). Neutral trials have distractor(s) that are neither compatible

nor incompatible with the target(s). For example, if targets are the colors red or green, but the

distractor is the word "BLACK", then the distractor is neutral. As described below, the Stroop

task (Stroop, 1935), the Simon task (Simon, Craft, & Small, 1971), and the Eriksen Flanker task (Eriksen & Eriksen, 1974) are all used to measure stimuli-specific effects because congruent, incongruent, and neutral trials are intermixed in these selective attention tasks. By contrast, task effects in selective attention involve the comparison between two types of tasks (Garner, 1974); a baseline task in which the distractor is held constant (or absent) across a set of trials and a filtering task in which the target and distractor are varied orthogonally (e.g. all combinations of target and distractor stimuli are presented randomly). The Stroop, Simon, and Eriksen Flanker tasks are collectively called conflict tasks because they probe selective attention by introducing conflict either between stimuli or between a stimulus and a response.

Stroop (1935) was interested in the level of interference in attention caused by conflicting stimuli. He printed names of colors using colored ink that was different from the printed word such that each word was printed in a color different from its meaning. For example, the word red was printed in blue ink, the word green was printed in purple ink, and so on. Stroop (1935) instructed participants to say the name of the ink color, instead of reading the word. For example, the word green printed in blue ink was to be called blue, and the word red printed in purple ink was to be called purple, and so on. This list contained trials that are now termed as incongruent trials. Stroop compared the participants' responses from the incongruent list to another task in which participants simply named solid color squares (neutral trials). It took the 100 participants 47 seconds longer (74.3% increase) on average to read the incongruent list, in comparison to the neutral list (Stroop, 1935). Stroop (1935) addressed how the incompatibility in the stimuli (from the incongruent trials) introduces conflict and interference when the semantic meaning of the word does not match the physical characteristics of the word. This interference, measured as the

difference in performance between incongruent and congruent (or neutral) trials, is now termed the *stroop effect.*

The Simon task is a spatial compatibility task used to test selective attention capabilities (Simon, Craft, & Small, 1971). This task measures the delay in RTs when the spatial location of a stimulus is incompatible with the intended response location, defined as an incongruent trial. For example, when a participant is instructed to click either left or right to a target feature (e.g. tone pitch; how vs. low) presented randomly in the left or right ear, the response is normally faster when the lateral position of the stimulus matches the lateral position of the response (congruent) than when they mismatch (incongruent). This delay in response is now termed the *Simon effect.*

Eriksen and Eriksen (1974) studied the effects of distractors in a non-search task called the Flanker task, in which target letters appeared at an expected location. In their paradigm, participants were simultaneously presented with a target letter and three distractor letters (called *flankers*) on either side; participants were instructed to respond by pressing a lever to the left if the target letter was either an H or a K and pressing the lever to the right if the target letter was either an S or a C (responses were counterbalanced across participants). Eriksen and Eriksen (1974) designed six conditions for target presentation, one of which was a control condition in which the target appeared alone without any flankers, and five conditions varying in flanker compatibility. The latter conditions were: (1) target and flankers are the same (e.g. target is K and the flankers are Ks); (2) target and flankers are response compatible (e.g. target is K and the flankers are Hs); (3) target and flankers are response incompatible (e.g. target is K and the flankers are Cs); (4) flankers are neither of the letters in the target set, instead they are other letters that share similar features with the target letter, based on the Gibson system, (e.g. the

target is H and the flankers are N W Z); (5) flankers are other letters not from the target set and do not share similar features with the target letter (e.g. target is H and the flankers are G J Q).

Eriksen and Eriksen (1974) also manipulated the space between the target and flankers across all the compatibility conditions such that the between-letter space was either 0.06°, 0.5°, or 1°. A three-way analysis of variance (ANOVA) of participants' RTs showed a significant main effect of both spacing and compatibility; participants responded much faster as the distance between the letters increased from 0.06° to 1°, and responded slowest across the three between-letter spacing for the third condition in which the target is flanked by distractors that demand the opposite response. Eriksen and Eriksen (1974) proposed that despite knowing exactly where the target letter would be presented, the flankers that are response incompatible to the target (e.g. condition three above; also termed an incongruent trial) elicit the slowest response, because they cause the most interference in target processing, commonly termed the *flanker effect*, measured as the difference in performance between congruent and incongruent trials.

Garner (1974) investigated task effects in the processing of stimuli composed of separable dimensions, such as color and shape, versus integral dimensions, such as saturation and brightness. Participants performed judgements of stimulus values in baseline and filtering tasks. Garner found that with separable dimensions participants performed comparably on filtering tasks (distractor random) and baseline tasks (distractor constant). However, with integral dimensions participants performed better when task-irrelevant stimuli were kept constant as task-relevant information varied (baseline tasks), in comparison to when task-irrelevant stimuli randomly varied across trials (filtering tasks). The filtering trials introduce uncertainty to the task by randomly pairing the task relevant and irrelevant information together, which results in a poorer task performance, known as *Garner interference.* Garner interference can be measured in

conflict tasks such as the Eriksen Flanker task by presenting incongruent trials among the congruent and neutral trials in the filtering condition in comparison to presenting just neutral trials in the baseline condition (Melara et al., 2002).

In the traditional view, there is one mechanism of selective attention: the activation of relevant information. Target activation and processing have been the focus of attention mechanisms because behavioral measures are restricted to recording performance in response to target stimuli. Fortunately, in recent years, the investigation of neural correlates has allowed researchers to gain a more in-depth understanding of the mechanisms of selective attention. Consequently, researchers are now capable of probing neural correlates in response to both relevant and irrelevant information, and this has indicated that there are two underlying mechanisms of selective attention – target enhancement and distractor suppression. Recent research suggests that these two attentional mechanisms function concurrently for executive control tasks, during which relevant information is enhanced and irrelevant information is inhibited to allow for optimal processing (Melara et al., 2002; Couperus & Mangun, 2010; Noonan, Adamian, Pike, et al., 2016). Selective attention, therefore, likely involves two co-occurring mechanisms of attention, one involving focus on important information, perhaps the task relevant target or an important stimulus in the environment, and the other on information that is ignored and suppressed from processing (Bridwell & Srinivasan, 2012).

Electrophysiological Research

One of the many methods of acquiring neural data is through electrophysiological means, specifically, through electroencephalogram (EEG) research, a non-invasive, safe, and inexpensive research method. EEG procedures are commonly utilized to retrieve event-related potentials (ERPs) to better understand the underlying neural mechanisms. Traditional ERP

analysis produces positive or negative voltage waveforms in response to the repeated time-locked triggers, after the random noise is cancelled out by signal averaging (Roach & Mathalon, 2008). However, components of ERP provide a generalized view of neural activity which encompass all frequency bands corresponding to the time-locked triggers. In order to develop a clearer understanding of frequency-specific neural activity in response to stimuli, frequency bands within the ERP waveform must be decomposed and analyzed. A technique called time-frequency analysis has recently gained momentum in cognitive research and provides promising methods for analyzing frequency-specific bands time-locked to the triggers of interest. Both ERP waveforms and time-frequency oscillations provide meaningful insight into the mechanisms and components of selective attention.

Event-related potentials. ERPs are averaged waveforms, time-locked to a repeated stimulus across multiple trials. The averaging of the signal across the many trials allows for the "noise" to be cancelled thus producing a clear neural signal in response to the time-locked trigger (Figure 1). When an ERP waveform is produced, the peaks and troughs are the positive and negative oscillations, respectively. The peak can occur either early in processing, such as the Auditory Brainstem Response which happen approximately 20 ms after stimulus onset or late in processing, beginning 50 ms after stimulus onset. The first late positive peak is termed P1, occurring approximately 100 ms after stimulus onset, followed by N1 (the first negative trough), followed by the second positive peak, P2, and so on. ERP waveforms have been widely used in understanding the neural responses during a cognitive task and have been linked to attentional components. Three ERP components are especially relevant to attention processing: N2, P3, and RP.

N200 (N2). The N2 ERP component is a negative waveform peaking 200-400 ms after target onset with neural sources in the dorsal anterior cingulate cortex (dACC) in response to conflict detection and resolution (Mathalon, Whitfield, & Ford, 2003). The amplitude of N2 is relatively larger on trials involving incongruent target and distractor stimuli than congruent stimuli (Silton, Heller, Towers et al., 2010). An increase in N2 amplitude on incongruent trials corresponds to the inhibition of a conflicting response (Purmann, Badde, Luna-Rodriguez & Wendt, 2011).

P300 (P3). The P3 waveform, occurring approximately 350-600 ms after trigger onset, has been observed in tasks requiring stimulus discrimination and is associated with the mechanisms of attention and memory (Polich, 2007). The function of the P300 waveform (used interchangeably with P3) was introduced by Sutton, Braren, Zublin and John (1965) and has been the focus of cognitive investigations since. Studies have reported an increase in P3 magnitude during target processing (Picton, 1992; Schupp, Junghöfer, Weike, & Hamm, 2003) as well as its involvement in distractor suppression (Polich, 2007). P3 amplitudes also vary as a function of individual differences such as arousal; individuals with high levels of arousal display higher levels of P3 amplitudes, in comparison to individuals with low levels of arousal (Stenberg, 1992). Also, more emotionally arousing and salient stimuli correspond to higher levels of P3 amplitude (Picton, 1992). An increase in P3 amplitude occurs during target discrimination (Duncan-Johnson & Donchin, 1982) and decreases as task difficulty increases, suggesting greater use of attentional resources (Kok, 2001; Kramer, Wickens & Donchin, 1985). The P3 component may have an inhibitory function focused on suppressing extraneous stimuli processing. Polich (2007) suggests that a low P3 amplitude during difficult tasks can be explained by more inhibitory control required by the high cognitively demanding task which

limits the attentional resources available for allocation. Hence, the P3 amplitude is dependent on task demands and stimuli properties.

   Rejection positivity (RP). Rejection positivity (RP) is a slow-wave neural response beginning 200 ms after stimulus onset and lasting 400 ms or more thereafter. The RP component has been linked to distractor processing during selective attention tasks (Melara et al., 2002; Münte, Spring, Szycik, & Noesselt, 2010). The RP component peaks positively in the ERP waves corresponding to the distractors or the unattended irrelevant stimuli, suggesting active suppression/rejection of the distractors.

   Time-frequency analysis. Our brains elicit neural responses to both external and internal stimuli and those neural responses can range within a frequency of 0 Hz to over 80 Hz. Hans Berger was the first to conduct an EEG and observe neural activity from the scalp and noticed that alpha oscillations which range from 8-12 Hz predominate. In addition to alpha oscillations, delta waves (0-4 Hz), theta waves (4-8 Hz), beta waves (12-30 Hz), and gamma waves (>30 Hz) are other frequency bands prevalent in our neural response activity (Herrmann, Grigutsch & Busch, 2005). Başar, Başar-Eroglu, Karakas,and Schürmann (1999) reviewed how different neural frequencies are active under different mechanisms of cognitive processing. The recorded activity in an EEG contains neural oscillations of all frequencies in the time-domain. Time-frequency analysis allows the breakdown of all the oscillatory activity based on the frequency band of interest as a function of time, hence allowing the analyses of individual frequency bands in response to different tasks and stimulations.

   Time-frequency analysis is a method of extracting neural data in both the 'time' and 'frequency' domains for non-stationary signals, which differs from traditional ERP methods that present waveforms in only the 'time' domain (Avanzo, Tarantino, Bisiacchi, & Sparacino, 2009).

The extraction of frequency-specific oscillations allows researchers to individually investigate the specific bands of frequency as a function of time. This analysis extracts the changes in oscillatory power specific for a frequency of interest, time-locked to a stimulus. Hence, the neural changes that are extracted after conducting a time-frequency analysis specify the time, the frequency, and the power for a repeated stimulus which can be visually represented in a spectrogram (Figure 2).

The Morlet Wavelet transform is a technique commonly utilized to extract the frequency bands from raw EEG data to produce transient signals in the time and frequency domains. The Morlet wavelet (see Figure 3) is a convolved windowed transform function that employs a Gaussian envelope and a sinusoidal wave to generate the magnitude and phase information for any given frequency, in the form of complex numbers for each time-point in the designated EEG epoch (Roach & Mathalon, 2008). The Wavelet transform is able to uncover neural activity specific for a range of frequencies, despite being embedded in noise caused by muscle movements or cognitive impairments (Blanco, Figliola, Quiroga, Rosso, & Serrano, 1998). Blanco and colleagues (1998) reported that the extraction process is very fine-tuned to a specific frequency or range of frequencies thus allowing researchers to extract and monitor oscillatory signals for specific frequency bands. Frequency band measures are commonly independent of one another, in contrast to ERP data, which often contains overlapping neural activity (Bernat, Nelson, Holroyd, et al. 2008).

The neural oscillations can be characterized by their phase and magnitude. The magnitude refers to their amplitude which is the intensity or power of an oscillatory frequency (Roach & Mathalon, 2008). The phase of an oscillation refers to the onset of the oscillation relative to a trigger stimulus and can be either induced or evoked (Galambos, 1992; Tallon-

Baudry & Bertrand, 1999). Induced activity jitters across trials and is not strictly phase-locked to

the experimental stimulus. By contrast, evoked activity is completely phase-locked to the

stimulus onset appearing at the same time after a trigger across multiple trials. Induced activity

nearly cancels out when averaged across trials because of the variation in oscillatory activity

across time whereas the averaged evoked activity results in an oscillatory waveform

representative of the neural response to the triggering stimuli (Herrmann, Rach, Vosskuhl, &

Strüber, 2014).

Different methods have to be applied to extract both induced and evoked oscillatory

activity from raw EEG data. Evoked activity (but not induced activity) can be derived from the

time-locked ERP waveforms. The ERP waveforms are subjected to a wavelet transform which

depicts the evoked neural oscillations in the time and frequency domains of interest. However,

induced activity is cancelled out in the averaged ERP because of the difference in latency across

trials. Therefore, to extract induced oscillations, evoked activity must be subtracted from the total

activity. To calculate the total activity, the raw EEG data must first undergo wavelet

transformation to produce absolute power values for each trial which then must be averaged

together to produce total activity containing both evoked and induced oscillations (Herrmann et

al., 2014; see Figure 4). Studies have shown that different cognitive processes and mechanisms

are associated with induced and evoked oscillations of a frequency band, making it imperative to

separately analyze both oscillatory activities (Foster, Sutterer, Serences, Vogel & Awh, 2016;

Freunberger, Fellinger, Sauseng, Gruber & Klimesch, 2009; Klimesch, Doppelmayr, Russegger,

Pachinger & Schwaiger, 1998; Tallon-Baudry, Bertrand, Delpuech, & Pernier, 1996). For

example, Tallon-Baudry, Kreiter, and Bertrand (1999) recorded gamma and beta band activities

as participants completed a visual short-term memory task; they found that only induced

oscillations were involved with memory processing. Additionally, Klimesch et al. (1998) reported that only the induced lower alpha band decreases in amplitude in response to targets and warning signals during an oddball paradigm. However, individual cognitive mechanisms simultaneously employ frequency oscillations of multiple bands (Roopun, Kramer, Carracedo et al., 2008) thus an individual frequency band may recur across multiple cognitive mechanisms (Ainsworth, Lee, Cunningham et al., 2011).

The use of time-frequency analysis has allowed researchers to investigate the specificity of neural oscillations in cognitive processing mechanisms. Demiralp, Yordanova, Kolev, and colleagues (1999) conducted a time-frequency analysis of ERP data on participants who completed an auditory oddball paradigm. Demiralp et al. (1999) separately analyzed neural activity in the delta, theta, and alpha ranges to measure the oscillatory correspondences to distinct cognitive processes. Kucewica, Cimbalnik, Matsumoto, et al. (2014) demonstrated how memory processing is associated with high frequency bands, specifically the induced gamma band (>30 Hz) oscillations. Similarly, van Driel, Sligte, Linders, Elport, and Cohen (2015) reported a strong link between conflict resolution, measured as participants completed a spatial response conflict task (e.g. the Simon task), and theta band oscillations. Furthermore, the role of beta oscillations has been strongly linked to linguistic capabilities, specifically language processing (Weiss & Mueller, 2012). Despite the prevalence of multiple neural oscillations in cognitive functioning, alpha waves (8-12 Hz) are noteworthy for their significant role in selective attention mechanisms.

Alpha Oscillations

Alpha oscillations (8-12 Hz) are the dominant cortical oscillations. They are strongly associated with physical and mental relaxation, indicative of an idle state of mind (Pfurtscheller,

Stancák & Neuper, 1996). They are readily apparent in EEG recordings whenever a participant closes his or her eyes and begins to relax. Yet, this traditional view of alpha waves has been updated recently (Başar, Schürmann, Başar-Eroglu, Karakaş, 1997). Klimesch (2012) reports that alpha oscillations are distinct from all other oscillatory bands, except slow beta waves, because they increase and decrease in amplitude in response to time-locked stimuli. These changes in amplitude to a time-locked trigger are called event-related synchronization (ERS; amplitude increase) or event-related desynchronization (ERD; amplitude decrease) (Pfurtscheller, 2001). Generally, all active neural oscillations increase in magnitude, displaying ERS, in response to a task or stimuli. Alpha waves, however, display ERD in response to task-relevant stimuli and ERS in response to task-irrelevant stimuli (Pfurtscheller, 2001; Klimesch, 2012).

Alpha oscillations have been associated with several distinct cognitive processes. These include alpha band desynchronization when encoding episodic memories (Minarik, Berger, & Sauseng, 2018) or using semantic long-term memory (Klimesch, 1999), communicating between frontal and posterior brain regions (Clayton, Yeung, & Cohen, 2017), or shifting attention between working memory and task demands (van Moorselaar, Foster, Sutterer, 2018), and alpha band synchronization in response to targets during an auditory oddball paradigm (Yordanova & Kolev, 1998) or as target discrimination abilities improve (van Dijk, Schoffelen, Oostenveld & Jensen, 2008). Interestingly, studies have shown that alpha rhythms are reflective of individual attributes such as intelligence (Doppelmayr, Klimesch, Stadler, Pöllhuber, Heine, 2002), performance (Klimesch, 1997; Klimesch, Schimke, Doppelmayr, Ripper, Schwaiger, & Pfurtscheller, 1996), and level of education (Begum, Reza, Ahmed, Elaina & Abdullah, 2011).

Alpha band activity divides into lower (8-10 Hz) and upper (10-12 Hz) alpha subbands, which are associated with different cognitive processes and may function independently (Klimesch, 1999; Jaušovec & Jaušovec, 2000; Fink, Grabner, Neuper & Neubauer, 2005). For example, Doppelmayr et al. (2002) found that intelligence level, measured using memory tests, is related to the desynchronization levels of individual alpha subbands with the upper alpha band associated with the processing of semantic information and the lower alpha band involved in the encoding of new information. Additionally, studies have shown that the lower alpha band captures attentional processing such as alertness or arousal; whereas the upper alpha band corresponds to more task-specific requirements such as memory processing (Doppelmayr, Klimesch, Hödlmoser, Sauseng & Gruber, 2005; Klimesch, Doppelmayr, Pachinger & Russegger, 1997; Klimesch, Doppelmayr, Röhm, Pöllhuber & Stadler, 2000; Klimesch, Pfurtscheller & Schimke, 1992; Pfurtscheller, Neuper & Mohl, 1994).

Klimesch and colleagues (1996) used a memory paradigm to test participants' recall ability and found that good performers displayed higher ERD in the lower alpha band when recalling presented words whereas poor performers exhibited higher ERD in the upper alpha band. Furthermore, Klimesch (1997) reported that alpha oscillations are significantly higher for good performers compared to bad performers during information encoding, retrieval, and during resting alpha. Another study compared alpha oscillation power across education levels and reported higher alpha power for participants in the lower education group, compared to participants in the higher education group, prompting the authors to link low cognitive functioning to higher alpha power (Begum, Reza, Ahmed, Elaina & Abdullah, 2011). By contrast, Jaušovec (2000) reported that intelligent and gifted children exhibit lower alpha power

when solving complex problems, indicating lower cognitive functioning, yet more neural

interaction between various neural regions, indicating higher cognitive functioning.

Recent research on the alpha-band suggests that alpha oscillations are responsible for the

suppression of irrelevant distracting stimuli during information selection and processing, an

important aspect of selective attention mechanisms (Klimesch, 2012; Klimesch, Sauseng &

Hanslmayr, 2007; Foxe & Snyder, 2011; Händel, Haarmeier & Jensen, 2011; Kelly, Lalor, Reilly

& Foxe, 2006; Payne & Sekuler, 2014; Rihs, Michel & Thut, 2007; Toscani, Marzi, Righi,

Viggiano & Baldassi, 2010; Worden, Foxe, Wang & Simpson, 2000). Vanni, Revonsuo, and

Hari (1997) measured alpha activity in the parietal and occipital regions as participants

completed a visual discrimination task in which they detected stimuli that were either a coherent

object (target) or a non-coherent object (distractors) between masks. Vanni et al. (1997) reported

that participants displayed significantly higher levels of alpha-band activity when presented with

non-coherent objects in comparison to being presented with coherent objects. Additionally, for

trials not requiring discrimination, the difference in alpha-band activity disappeared, prompting

the researchers to suggest an inverse relationship between alpha enhancement and stimulus

salience (Vanni et al., 1997). Worden and colleagues (2000) investigated the role of alpha

oscillations in a spatial cueing paradigm using visual stimuli to measure alpha levels in the

anticipatory period between cue and target presentation. Ten healthy participants completed 16

trials containing two types of target stimuli: motion-discrimination and orientation-

discrimination. For each, participants were cued for 35 ms to the location of the target 1000 ms

prior to the target presentation. Furthermore, the non-cued location presented an irrelevant

distractor in half the trials, prompting the participants to actively ignore the non-cued location

(Worden et al., 2000). The researchers reported higher levels of alpha rhythms in the cortical

region ipsilateral to the cued location, such that when the participants were cued to the right, there was an enhancement in alpha oscillation in the right parieto-occipital region (Worden et al., 2000). Worden and colleagues (2000) suggested anticipatory active suppression of the non-cued left location where a distractor is likely to appear, as evident by the increased alpha oscillation.

Kelly et al. (2006) elaborated on Worden and colleagues' (2000) findings by investigating whether the relative difference in alpha power across regions corresponding to the target and distractor locations was a result of alpha ERD (reduction in alpha amplitude from target processing), alpha ERS (enhancement in alpha amplitude from distractor processing), or both. Kelly and colleagues (2006) instructed 10 healthy participants to maintain fixation on a central cross, which also served as a cueing stimulus, while keeping count of the target presentation in the cued location and ignoring the stream of stimuli in the non-cued location. Consisting with Worden and colleagues' (2000) findings, the results revealed an alpha ERS in the cortical region contralateral to the non-cued location, peaking after cue presentation (Kelly et al., 2006). The researchers concluded that the alpha-band functions as an active suppression mechanism in which bilaterally presented targets and distractors with shared features can be processed separately (Kelly et al., 2006). Furthermore, Rihs and colleagues (2007) designed a visuospatial cueing go/no-go paradigm to investigate whether alpha oscillations display ERD and/or ERS in the absence of distracting stimuli; they argued that previous findings displayed alpha ERS as a result of task-demand, rather than a reflection of a general neural mechanism (e.g Worden et al., 2000; Kelly et al., 2006). Rihs et al. (2007) instructed 12 participants to maintain focus on a central cue fixation point that was surrounded by eight squares serving as possible target locations. The central cue was an arrow presented for 80 ms, 1300 ms prior to target presentation, which pointed in the anticipated target location and was valid in 88% of the trials.

The target was either a go (elicit response) or no-go (withhold response) stimulus. The topography results showed an increase in alpha amplitudes corresponding to the non-target areas, contralateral to the unattended position, suggesting that alpha rhythms are not only specific for distractor suppression, but are also prevalent in suppressing the processing of unattended locations (Rihs et al., 2007).

Recent studies have demonstrated that alpha oscillations, similar to visuospatial attention, are also involved in feature-based suppression, independent of spatial discrimination. Snyder and Foxe (2010) designed a visual cueing paradigm to test the shifting of the alpha-band activity across the dorsal and ventral streams. Hence, 12 participants were cued to the feature of the upcoming target which was either a "color" (employs ventral stream) or a "motion" (employs the dorsal stream) discrimination. Source localization of the cue-to-target interval revealed that alpha power was greater in the dorsal stream when color was cued (e.g. motion was suppressed) and greater in the ventral stream when motion was cued (e.g. color was suppressed; Snyder & Foxe, 2010). The authors suggested that increases in alpha power prior to target presentation reflect the preparatory suppression of the irrelevant distractor features, consistent with the role of alpha oscillations in visuospatial paradigms (Worden et al., 2000; Kelly et al., 2006; Rihs et al., 2007). To further examine the role of alpha oscillations in preparation for distractor suppression, Bonnefond and Jensen (2012) investigated the role of anticipated distractors on alpha oscillations as participants completed a modified Sternberg working memory task. Anticipated distractors were introduced as participants retained new information; the results showed a significant increase in alpha power prior to distractor presentation (Bonnefond & Jensen, 2012). Interestingly, Bonnefond and Jensen (2012) reported that performance was significantly better on trials in which alpha power displayed higher synchronization, suggesting that alpha oscillations

may serve as performance predictors. Similarly, Händel, Haarmeier, and Jensen (2011) reported

that better motion detection and improved visual distractor suppression corresponds to higher

alpha activity, indicating that alpha oscillations actively suppress information outside the target

zone of attention. Therefore, alpha oscillations are an integral component of selective attention

mechanisms as they are directly associated with reducing distractor processing and inducing

inhibitory control for improved target assessment (Klimesch et al., 2007).

Cognitive Training

A growing body of evidence points to the use of attentional training to improve executive

functions, including selective attention, to yield improvements in both behavioral performance

and neural activity. Mechanisms of selective attention are intertwined with other processes of

executive functioning, including inhibitory control and interference resolution, which must be

examined separately to ascertain whether selective attention and its components are amenable to

training. Inhibitory control is a central feature of selective attention used to suppress distractors

while attending to task-relevant information (Barkley, 1997). Similarly, interference resolution is

a component of selective attention responsible for ignoring irrelevant stimuli (e.g. distractors)

that interfere with target processing (Millner, Jaroszewski, Chamarthi, and Pizzagalli, 2012; Nee,

Wager & John, 2007).

As previously discussed, Stroop (1935) found that participants experienced a high level

of interference measured by their slow response times when instructed to name ink colors of

color names mismatched with the ink. Stroop (1935) also examined the effects of training on

attentional interference. He conducted 14 practice sessions with 32 participants using the same

stimuli to determine whether interference in attention can be reduced with training. Interestingly,

Stroop (1935) found that after acquiring a sufficient amount of practice naming the ink colors of

incongruent trials, participants improved in their response times, albeit with considerable

variability among participants. Stroop (1935) suggested that although interference levels can be

reduced by training, they cannot be completely eliminated. The effects of training on response

times suggested that training effects are dependent on the participants' previous level of

cognitive functioning (Diamond & Lee, 2011).

Thorell and colleagues (2009) conducted a five-week (25 session) training study with

healthy preschool children divided among four groups: two training groups, one active control

group, and one passive control group. The trainings groups were designed to improve either

working memory (working memory training group) or inhibitory control through computer

games (inhibition training group). Participants in the active control group played commercial

computer games that did not rely on working memory or inhibitory control function. Lastly, the

passive control group only participated in the pre- and post-test sessions. During the inhibition

training, the Eriksen flanker task (Eriksen & Eriksen, 1974) was one of three tasks used (the

other two being Go/No-Go and Stop Signal tasks); in this a target stimulus was flanked by

interfering distractors (congruent trials: target and distractor arrows were oriented in the same

direction; incongruent trials: target and distractors were oriented in opposite directions); as

training progressed, the difficulty increased by decreasing the allotted response time.

Thorell et al. (2009) reported that the children improved in all the training tasks over the

five-week training period, particularly in the flanker task. The analyses of the testing sessions

revealed that the children in the working memory training group improved significantly on the

non-trained tasks, whereas children in the inhibition training group improved on the individual

tasks, but not on the non-trained tasks compared to the control groups. It was proposed that

inhibitory control is perhaps less suitable for manipulations of difficulty and is non-transferable

across tasks compared with working memory. The transference of skills typically occurs when the underlying mechanisms and activated neural regions in both training and test are the same, suggesting that Thorell and colleagues (2009) tested and trained the children in tasks that did not share a common neural mechanism (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008). Contrary to the outcome of Thorell and colleagues' (2009) experimental training, Berkman, Kahn, and Merchant (2004) found that inhibitory control is suitable for manipulation of difficulty and is amenable to training.

Berkman and colleagues (2014) conducted a training study using a Stop-Signal Task (SST). The SST is commonly used to test inhibitory control because it instructs the participant to respond to specific triggers, except when the "stop-signal" is also presented, which prompts the participant to withhold his or her response (Logan, 2015; Verbruggen & Logan, 2008). This task measures how well a participant is able to inhibit a response, even after it has been elicited by the presence of the cueing stimulus, often called the go-signal. Berkman et al. recruited 60 participants in a three-phase training study, consisting of a baseline phase, followed by a training phase, and concluding with an endpoint phase. During both the baseline and endpoint phases, participants completed the SST paradigm while their neural data was collected using fMRI.

The SST instructed participants to press the left or right arrow key when they saw an arrow (pointing either left or right) serving as the go-signal, but were instructed to withhold their response when a sound was played (stop signal) after the go signal appeared at varying delays. The delay between the go signal and the stop signal was termed stop-signal delay (SSD; Berkman et al., 2014). For the training phase, participants were randomly assigned to either the experimental training group (trained in SST) or the control group (sham-SST training with no stop-signals), completing 10 sessions of training over a period of three weeks. The experimental

group was trained in the SST as the SSD was adaptively manipulated to incrementally increase

difficulty level (Berkman et al., 2014). To measure inhibitory control, Berkman and colleagues

(2014) calculated the difference between the stop signal processing speed and the SSD, which

they termed the stop-signal response time (SSRT).

Berkman and colleagues (2014) reported that over the course of the 10 training sessions,

participants in the experimental group gradually improved in the efficiency of their inhibitory

control process. A significant interaction between group (training and control) and phase

(baseline and endpoint) was found, revealing that participants in the training group improved in

inhibitory control processing after training, compared with the sham-training. Consistent with the

behavioral data, neural changes were also evident in the training group after training; activity in

the inhibitory control network increased when the go-signal was presented, suggesting a higher

level of alertness and control over the response. Interestingly, activation in the network to the

stop-signal decreased after training, suggesting that activation shifted as a result of training to

focus more on the go-signal cue. Berkman and colleagues concluded that components of the

inhibitory control network are amenable to training, using an SST in which difficulty is adapted

to the participant's performance.

Rueda, Rothbart, McCandliss, Saccomanno, and Posner (2005) were the first to test the

effects of cognitive training on attentional control in children. They measured the children's

attentional abilities using a modified child version of the Attention Network Test (Child ANT),

designed by Rueda, Fan, McCandliss, Halparin, Gruber, Lercari, and Posner (2004). The Child

ANT used a flanker task to measure children's selective attention, primarily their ability to

ignore distractors that are conflicting with the targets (Rueda et al., 2005). Children responded to

the orientation of the center target (fish stimulus), simultaneously flanked by distractors (fish

stimuli) that were the same or opposite in orientation as the center fish. The difference in the RTs

between congruent and incongruent trials was used to derive a *conflict score.* The presence of

incongruent trials has been shown to activate the attention network, which encompasses attention

related capabilities (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003). Rueda and

colleagues (2005) recruited a total of 73 children (49 children were 4 years old and 24 children

were 6 years old) to participate in the study. The participants completed the Child ANT task as

their neural waves were recorded using EEG procedures, before and after training. The five-day

training, administered to the experimental group, was designed to train processes of selective

attention, such as stimulus discrimination, conflict resolution, and inhibitory control, using child-

friendly games that increased in difficulty as training progressed.

Rueda et al. (2005) reported that children in the experimental group had a lower conflict

score after training, relative to controls. Interestingly, the training "matured" the four year olds

and the six year olds, such that their responses after training mimicked those of older children or

adults, respectively. From the neural data, the N2 ERP waveform representing conflict resolution

for incongruent trials also increased after training which was consistent with the behavioral data.

A reduced conflict score corresponded to a less negative N2 waveform in the anterior cingulate

cortex in line with past literature (Bush, Luu, & Posner, 2000; Rueda et al., 2005; Silton et al.,

2010; Van Veen & Carter, 2002). Rueda and colleagues (2005) provided further evidence that

cognitive training does impact both behavioral performance and neural correlates.

Rueda, Checa, and Cómbita (2012) designed a training protocol to analyze the immediate

and short-term implications of cognitive executive function training on selective attention

capabilities and its corresponding neural activations in preschool children. Rueda and colleagues

tested the 37 participating children on three different occasions: prior to training, immediately

after training, and two-months after training; EEG data were recorded during all three testing

session. The testing protocol was the Child ANT task (Rueda et al., 2004; 2005) using a

modified version of the Eriksen flanker task (Eriksen & Eriksen, 1974). Rueda et al. (2012)

randomly assigned 19 of the 37 children to the experimental group, with the rest assigned to the

control group. The experimental group underwent ten sessions of computerized cognitive

training, mimicking the training implemented by Rueda and colleagues (2005), focusing on

aspects of selective attention such as discrimination, conflict resolution, and inhibitory control.

Interestingly, performance of children in the training group did not improve significantly in the

Child ANT task relative to the controls, suggesting that more repetition of the task may have

contributed to the improved performance across both the trained and untrained participants,

resulting in a ceiling effect. However, significant changes in the N2 ERP component were found

in response to the incongruent trials for the trained participants at both post-test sessions

(immediately after training and two months after training), suggesting that training affected

neural correlates of response inhibition and induced changes that were maintained long-term

despite training being discontinued. Rueda and colleagues (2012) proposed that training

interventions may need to be long-term, including intensive sessions that continuously challenge

the child's attentional capabilities.

A study conducted by Millner and colleagues (2012) explored whether interference

resolution, an aspect of cognitive control which is involved in suppressing distractors that are

different from the targets (therefore an interference in attention), can be improved through

cognitive training. The pre- and post-test session were identical, consisting of a Flanker and

Stroop task, during which behavioral and electrophysiological data were recorded. To reiterate,

N2 amplitude becomes more negative during trials involving interference resolution and less

negative during trials with minimal conflict (Silton et al., 2010). This relationship served as the basis of the cognitive training for Millner and colleagues' (2012) study in which they controlled for interference resolution by using congruent (targets and distractors are identical) and incongruent or conflict (targets are opposite from distractors) trials. Millner et al. (2012) trained 18 healthy participants using the Simon task and tested them using the Flanker task, to assess transfer effects, recognizing that both tasks utilize interference resolution and activate similar neural regions, specifically the frontocingulate pathways. The behavioral results from the three training sessions revealed relatively worse performance during incongruent trials. However, a significant improvement in response time was shown from pre-test to post-test for incongruent trials, whereas no changes in response time were observed for congruent trials. The ERP analyses revealed that the magnitude of N2 to incongruent trials became more negative from pre- to post-test session, indicating less interference after training. This study demonstrated the transfer of skills between the trained and tested tasks which employed similar neural mechanisms and outlined the successful application of cognitive training to improve cognitive control. However, the study was limited because there was no control group and the targets and flankers were presented simultaneously, which prevented the researchers from disentangling the effects of training on target versus distractor processing.

Melara and colleagues (2002) strived to disentangle the two mechanisms of selective attention by conducting an ERP training study to assess the effects of target discrimination training and distractor suppression training using a dual-channel auditory selective attention task. Thirty-six participants were randomly assigned to one of the two types of training between testing sessions: inhibition training or discrimination training. During the inhibition training procedure, participants were instructed to attend to the target tones in one ear, while

simultaneously ignoring the distractor tones heard in the other ear. As training progressed, the

distractors became more difficult to distinguish from the targets, thus increasing the demand for

inhibitory control and distractor suppression. Alternatively, discrimination training instructed

participants to distinguish between target tones heard in one ear, without any distracting stimuli

present in the other ear. The recorded ERP waveforms, collected during pre- and post-test

sessions, were time-locked to the triggers, such that distractors and targets were presented

individually during a trial, allowing the neural response for each trigger to be individually

recorded and analyzed. The pre-and post-test sessions were identical and used an auditory

selective attention task containing baseline and experimental conditions. The baseline condition

had trials with targets and no distractors, whereas the experimental condition had targets

alongside distractors. All participants from both training groups completed the baseline and

experimental conditions before and after the three weeks of their assigned training (Melara, et

al., 2002).

Consistent with past literature, Melara and colleagues (2002) reported that participants

were less accurate and took longer to respond to the experimental trials in comparison to the

baseline trials, because the presence of the distractors in the experimental condition interfered

with target processing. Participants in the inhibition training group improved to a greater degree

compared to participants who received discrimination training, suggesting that training aimed at

suppressing interfering distractors is more beneficial than training aimed at differentiating

between target stimuli. ERP measurements revealed elevation from inhibition training in RP, a

slow wave to the distractors (Chen & Melara, 2014), and a reduced P3 amplitude to distractors

from inhibition training, in line with behavioral performance, suggesting the training effects to

be inhibition-specific. Melara, Tong, and Rao (2012) found these gains in performance to be

retained even four weeks after training, with enhancement in RP growing during the follow-up period, despite no further training. Melara and colleagues (2012) also found that participants were less distracted by the irrelevant stimuli and more sensitive to the targets after inhibitory control training, concluding that efficient implementation of auditory selective attention training actively improves distractor suppression.

Present Study

Researchers have sought to train participants in selective attention by trying to improve inhibitory control (Melara et al., 2002; Thorell et al., 2009; Berkman et al., 2014) or conflict resolution (Rueda et al., 2005; Millner et al., 2012). However, no study has combined inhibitory control and conflict resolution to assess the effects of inhibitory control training on resolving conflict. Consequently, the next step in addressing the cognitive training of visual selective attention was to investigate the role of the disentangled mechanisms of selective attention using inhibitory control training that focuses on conflict resolution.

In the present study, participants were trained in either discrimination training or inhibitory training using a modified version of the visual Eriksen flanker task (Eriksen & Eriksen, 1974), termed the temporal flanker task. This task allowed us to collect separate electrophysiological recordings in response to targets and distractors for each trial. Pertinent to our interest in selective attention and its mechanisms, the frequency band for alpha waves were analyzed because of their prominent role in distractor suppression and inhibitory control (Foxe & Snyder, 2011; Hanslmayr, Gross, Klimesch, & Shapiro, 2011; Klimesch, 2012; Klimesch et al., 2007). Consequently, ERP waveforms and alpha-band activity to targets and distractors were measured before and after training.

We had three specific aims and hypotheses for this study pertaining to the effects of cognitive training on the corresponding behavioral and neural correlates. We aimed to investigate changes in behavioral performance as a result of both discrimination and inhibition training. We hypothesized that inhibition training would yield relatively greater improvements in behavioral performance, as measured by reductions in Garner interference and the congruity effect. Our second aim was to further disentangle the mechanisms of selective attention by analyzing training induced changes in ERP waveforms. We hypothesized that discrimination training would produce better target processing, as measured by increases in the N2 congruity effect, whereas inhibition training would produce better distractor inhibition, as measured by increases in distractor RP component. Lastly, we aimed to examine the effects of cognitive training on alpha oscillations. We anticipated greater alpha ERS (distractor suppression) in response to inhibition training and greater alpha ERD (target processing) from discrimination training. Overall, we sought to investigate whether inhibition training and discrimination training differentially affect stimulus processing using a fine-grained analysis of the processes involved in the detection and resolution of conflicting stimuli.

Methods

Participants

Thirty-six healthy students (25 females, mean age = 20.36 years) participated in this study for course credit. Data from two participants were omitted from analysis for lack of completion. All participants provided informed consent forms (and assent forms when applicable). All participants had normal, or corrected-to-normal vision, and no self-reported history of neurological disorders. Participants were randomly assigned to either discrimination training (18 participants; 13 females) or inhibition training (18 participants; 12 females). The

Institutional Review Board at City College, The City University of New York approved the

protocol.

    Demographics. The Edinburgh Handedness Inventory (Oldfield, 1971) and demographic

data were collected for each participant, including their gender, age, ethnicity, and level of

education.

Stimulus

    All participants were tested individually, once a week at the same time of the day and in

the same location for five consecutive weeks. A modified version of Eriksen and Eriksen's

(1974) flanker task, termed the temporal flanker task, was utilized in all three phases of the

study: pretest (week 1), training (weeks 2-4), and posttest (week 5). Following the instruction

screen, a gray fixation square (.67° of visual angle) appeared followed by the three sequentially

presented visual stimuli (.38° of visual angle) which appeared in gray on a black background.

The first stimulus was a distractor, the second stimulus was the target, and the third stimulus was

also a distractor, identical to the first distractor. Each stimulus appeared for approximately 150

ms with a varying and randomly distributed inter-stimulus range between 153 ms and 390 ms.

During the task, the visual target was either a vertical or horizontal line whereas the distractors

were either the same orientation as the target (congruent trial), opposite orientation as the target

(incongruent trial), or crosses (neutral trial; see Figure 5). Participants were instructed to respond

to the orientation of the target stimulus as quickly and accurately as possible, while ignoring the

distractor stimuli.

    The temporal flanker task was used to record neural activity time-locked separately to

distractors and targets since distractors and targets were presented sequentially during a trial

(Melara et al., 2002). Although no prior study has used a time-locked version of the Eriksen Flanker task to analyze alpha-band activity, studies have reported alpha ERS and ERD in response to distractors and targets, respectively. Dissociating and analyzing the neural responses for target and distractor presentation is essential for detecting changes in alpha amplitudes (Worden et al., 2000; Kelly et al., 2006; Rihs et al., 2007). Classic conflict tasks entangle both target and distractor processing because EEG data is recorded as all stimuli are simultaneously presented in a trial. However, a clear advantage of the modified temporal flanker task is that it records the disentangled neural response to each stimulus because targets and distractors are separately presented, hence allowing for separate analysis of target and distractor processing.

Procedure

The study comprised three phases over a period of five weeks: pretest (week 1), training (weeks 2, 3, and 4), and posttest (week 5). Each participant was tested at week 1, prior to acquiring any training, and again at week 5, after three weeks of training, with one training session per week. The pre-test and post-test sessions were identical. During the first session of the study, each participant was informed of the purpose of the study, and asked to read, sign, and date the consent form (participants younger than 18 years were asked to provide consent from their parents and an assent form). Once the participant was informed of the voluntary and confidential nature of the study, he or she was assigned a participant number, and was randomly placed in either Training A (discrimination training; n = 18) or Training B (inhibition training; n = 18). Participants were blind to their type of training. The procedure is outlined in Figure 6.

During the testing sessions, the participant was prepared for EEG testing and seated in a dimly lit, electrically and acoustically shielded, Industrial Acoustics Company (New York) chamber at a distance of 60 cm from a Dell Model P1130 RGB computer monitor with a refresh

rate of 75 Hz. Stimuli were created in Presentation® (Neurobehavioral Systems). Throughout

both pre-test and post-test sessions, continuous EEG recordings were collected using a BioSemi

Active-Two system in a high-density montage, using 160 scalp electrodes, at a sampling rate of

512 Hz. Blinks and other eye movements were monitored by electrooculogram (EOG) from two

electrode sets, one on the infra- and supra-orbital ridges of the right eye (VEOG), the other on

the outer canthi of each eye (HEOG).

During the pretest and posttest phases, all participants completed 10 baseline blocks

followed by 10 filtering blocks (Garner, 1974) of the temporal flanker task while behavioral and

electrophysiological data were collected. Each block contained 100 trials. The baseline condition

consisted of 100% neutral trials whereas each filtering block contained 70% neutral trials (target

was flanked by crosses), 15% congruent trials (target and distractors were identical), and 15%

incongruent trials (target and distractors were opposite in orientation). The participant was

instructed to use the computer mouse with their right hand and to press either the right or left

mouse key (assignment counterbalanced across participants) to indicate target orientation

(vertical or horizontal line). Practice trials and short breaks were given to each participant

throughout testing. Participants repeated trials in which accuracy fell below 80% correct. The 10

sets of baseline and filtering blocks were completed by the participant as reaction time, accuracy

scores, and EEG data were collected for each trial during the pretest and posttest sessions. The

testing sessions, including the EEG preparation, lasted approximately four hours.

During the training weeks (weeks 2-4), the participant was required to arrive at the same

time of the week for the three consecutive weeks for the 1.5-2 hours of training. The participants

were randomly assigned to either discrimination training or inhibition training, each containing

24 blocks of 100 trials each. Discrimination training contained 100% neutral trials in which each

target was flanked by crosses. However, the target magnitude gradually increased in visual angle from .19° in week two to .29° in week three to .38° in week four, while the neutral distractor magnitude remained .57° throughout training. Alternatively, in inhibition training, which included 60% incongruent (target and distractors are opposite in orientation), 20% congruent (target and distractors are identical in orientation), and 20% neutral trials (distractors are crosses), the distractor magnitude gradually increased in visual angle from .19° in week two to .29° in week three to .38° in week four while targets were consistently .47° throughout this training.

EEG Data Recording and Analyses

EEG data were continuously recorded during the pretest and posttest sessions of this study at a sampling rate of 512 Hz using a BioSemi Active-Two system in a high-density recording of 160 scalp electrodes and eight facial electrodes, using an elastic cap. Trials containing mastoid activity exceeding 100 µV were rejected. Trials contaminated by blinks, eye movements, or other movement artifacts were defined as z-values on the VEOG, HEOG, and lowermost scalp channels exceeding 4.5 in a frequency band between 1 and 140 Hz. Artifact trials were removed automatically using a Matlab routine (Fieldtrip; Oostenveld, Fries, Maris, & Schoffelen, 2011).

Event-related potentials were restricted to trials with a correct behavioral response. The sweep time was 1200 ms, including a 200 ms pre-stimulus baseline. Signal-averaged waveforms were band-pass filtered between .1 and 30 Hz. ERP components were measured to the initial flanker separately for congruent, incongruent, and neutral stimuli. Distractor RP was defined as the average voltage to the initial flanker 600-1000 ms after stimulus onset and measured over seven frontal electrode locations: D7, D8, C18, C31, C32, D11, and D22 (Bidet-Caulet et al.,

2010). Analysis of variance (ANOVAs) of ERP amplitudes were designed with Training Group

(2 levels: Discrimination Training and Inhibition Training) as the between-subjects factor and

Test (2 levels: Pre-test and Post-test) and Congruity (2 levels: congruent and incongruent) as

within-subjects factors. All main effects and interactions reported as significant were reliable

after Greenhouse-Geisser correction (Greenhouse & Geisser, 1959).

A time-frequency analysis of the alpha band was computed using a Matlab routine to

assess the average alpha power, related to the first flanker for all incongruent trials, across both

trainings and testing periods. ERP analyses indicated that the greatest effects of training were

restricted to incongruent trials. Hence, only these trials were included in the time-frequency

analysis. Each participant responded to 15 incongruent trials per task, resulting in 150

incongruent trials (15 trials x 10 filtering tasks) in the pretest session and 150 incongruent trials

in the posttest session. Consequently, a total of 2,700 incongruent trials were recorded across

each training group per testing session (150 incongruent trials x 18 participants per training

group). Ultimately, the alpha power of 10,800 incongruent trials (150 incongruent trials x 18

participants per training group x 2 training groups x 2 testing sessions) was analyzed to assess

the band-specific training effects on distractor processing.

A Fieldtrip Toolbox routine using a Morlet wavelet transform was employed across both

the time and frequency domains for all correct trials to extract the mean power of the alpha

oscillation for both training groups (Oostenveld et. al., 2011). The Morlet wavelet is a windowed

transform function that employs a Gaussian envelope to generate the magnitude and phase

information for any given frequency, in the form of complex numbers for each time-point in the

designated EEG epoch. The magnitude information is then extracted from the complex number,

allowing it to be squared and averaged across trials to generate the mean power for any

oscillatory frequency (Roach & Mathalon, 2008). In this study, the windowed function was applied across all correct EEG trials, for both pretest and posttest, to extract frequencies in the alpha range (8-12 Hz) whose magnitudes were then converted to power values and averaged to retrieve mean alpha power for each time epoch at the designated regions of interest. Evoked alpha power and induced alpha power were extracted and analyzed separately. Evoked alpha power was derived from the spectral decomposition of the ERP data (phase-synchronized), whereas induced alpha power was derived by first extracting the alpha power from the EEG data, thereby preserving the phase information, and then measuring the mean alpha power (Roach & Mathalon, 2008).

The regions of interest were the parietal (Pz), parieto-occipital (POz), and occipital (Oz) sites, which corresponded with the biosemi locations: A19, A21, and A23, respectively, and were selected to be in line with past literature on alpha oscillations (Quiroga & Schürmann, 1999; Mathewson et. al., 2009; Johnson, Hamidi, & Postle, 2010; Begum, Reza, Ahmed, Elaina, & Abdullah, 2011). To confirm that alpha oscillations to the flanker were maximum at these sites, spectrograms of alpha power were generated and visually inspected for individual participants across various scalp regions. Output of the Morlet wavelet transform in the 8-12 Hz (alpha band) was converted to 'power' with a wavelet width of '3', as recommended by Fieldtrip for an increase in temporal resolution. To assess changes in alpha power across time during a single trial, four time epochs were defined: 0-100 ms, 100-200 ms, 200-300 ms, and 300-400 ms. Alpha power within each epoch was defined as average alpha power across 5 ms increments.

To normalize and reduce the variability of the output data, a logarithmic transformation was conducted and log-transformed alpha power was analyzed across training groups, testing periods, electrode sites, alpha frequencies, and time epochs. Log transformations have been

conducted on multiple studies to normalize oscillatory data (Kiebel, Tallon-Baudry & Friston, 2005; Ponomareva, Andreeva, Protasova et al., 2013; Yuvaraj, Murugappan, Ibrahim et al., 2014; Smulders, Oever, Donkers et al., 2018). Using IBM SPSS Statistics®, the log-transformed alpha band power for incongruent trials was assessed using mixed-model ANOVAs, with the participant Training Group (2 levels: discrimination training and inhibition training) as the between-subjects factor while the Test Time (2 levels: pretest and posttest), Electrode Site (3 levels: Pz, POz, and Oz), Frequency of Interest (5 levels: 8 Hz, 9 Hz, 10 Hz, 11 Hz, and 12 Hz), and Time of Interest (4 levels: 0-100 ms, 101-200 ms, 201-300 ms, and 301-400 ms) as the within-subjects factors. This analysis was conducted individually for both induced alpha power and evoked alpha power, post-log transformation.

Behavioral Data Recording and Analysis

Throughout the five sessions of the study, response accuracy (percent correct) and reaction times (RTs; in millisecond) were collected and averaged for all correct trials for all participants in each condition. Mixed model ANOVAs were performed on behavioral data using IBM SPSS Statistics® software, with Training Group (2 levels: Perceptual Training and Inhibitory Training) as the between-subjects factor, with Task (2 levels: baseline and filtering) and Test (2 levels: pretest and posttest) as within-subject factors. Congruity (3 levels: congruent, incongruent, and neutral) replaced Task in ANOVA during the analyses of flanker effects in filtering tasks. Garner interference was measured as the difference in performance between neutral trials in baseline and filtering task conditions, indicating the degree to which uncertainty from trial-to-trial change in stimulus type undermines selective attention (Garner, 1974). Stroop interference, which we termed the *congruity effect*, was measured as the difference in RTs and accuracies between incongruent and congruent trials to determine how match or mismatch

between target and distractor undermines selective attention (Stroop, 1935; Millner et al., 2012).

A reduced congruity effect corresponded to better target processing. An analysis of covariance

was conducted to account for group differences at pretest.

Results

Demographics

Twenty-five of the 36 participants in this study were females. The average age of all

participants was 20.36 years with a standard deviation of 2.66 years and range of 16-26 years. A

one-way ANOVA was conducted to compare ages across the training groups and it was found

that participant ages did not differ significantly between groups ($F(1, 34) = 0.95$, *ns*). From the

sample, 25% of the participants were White; 19.44% were Asian; 8.33% were Black or African

American; and 47.22% were Hispanic or Latino. Furthermore, 30.56% of the participants were

High School students; 55.56% were College students; 11.11% were College Graduates; and

2.78% were Graduate students. Table 1 outlines the sample demographics results across all

participants and between the training groups.

Behavioral Performance

The average RTs, accuracies, and their standard error (SE) are summarized in Table 2 for

both perceptual and inhibitory training groups across task (Baseline and Filtering: Neutral,

Congruent, and Incongruent trials) and testing session (Pre-test and Post-test). The correlation

between speed and accuracy was r=0.84, measured across both training groups, both testing

sessions, and all stimulus types, indicating no compromise between speed and accuracy.

Garner interference. The difference in performance (both RT and accuracy) between

the baseline and filtering tasks is measured as Garner interference. The ANOVA of RTs from the

behavioral data revealed a main effect of Task, $F(1,33)=108.39$, $p<.001$, $\eta^2=.11$, such that the

RTs were higher on average during the filtering task, in comparison to the baseline task,

revealing the interference in selective attention caused by the incongruent distractors during the

filtering task, in which 15% of the trials were incongruent. Although both training groups

displayed a significant reduction in Garner RT after training, $F(1,33)=21.08$, $p<.001$, $\eta^2=.02$, a

significant interaction between Group x Test, $F(1,33)=6.85$, $p=0.01$, $\eta^2=.005$, showed that

participants in the inhibitory training group had a greater reduction in Garner RT, in comparison

to the participants in the discrimination training group (see Figure 7). Therefore, the level of

improvement in selective attention from pretest to posttest is dependent on the type of training

the participant received. Furthermore, analyses of Garner accuracy revealed a main effect of

Task, $F(1,33)=45.92$, $p<.001$, $\eta^2=.37$, showing that the participants performed better on baseline

tasks, in comparison to the filtering tasks.

Congruity effect. The difference in performance within congruity is termed the

congruity effect. An ANOVA of RTs during the filtering task, which displayed congruent,

incongruent, and neutral trials, revealed a main effect of Congruity for RTs, $F(2,66)=171.31$,

$p<.001$, $\eta^2=.58$, and accuracy, $F(2,66)=87.19$, $p<.001$, $\eta^2=.79$. As shown in Figure 8, the

participants across both training groups and test sessions achieved highest accuracy and lowest

RT on congruent trials, in comparison to the lowest accuracy and slowest response times on

incongruent trials. Similar to Garner interference, congruity effect also declined after training, as

indicated in both RT [$F(2,66)=12.16$, $p<.001$, $\eta^2=.01$] and accuracy [$F(2,66)=16.47$, $p<.001$,

$\eta^2=.05$]; however, participants in the inhibition training group demonstrated lower congruity

effect after training, in comparison to the discrimination training group. This resulted in a Group,

Congruity, and Test interaction which was significant for congruity effect RTs, $F(2,66)=4.35$,

p=.02, η^2=.005, (see Figure 8) and marginally significant for congruity effect accuracy, $F(2,66)$= 2.77, p=.07, η^2=.01.

ERP Waveforms

N2 component. A main effect of Congruity in N2 peak amplitude to the target, $F(1,32)$= 20.16, p<.001, η^2=.22, showing that the N2 amplitude was significantly greater on incongruent than congruent trials. Training increased the amplitude of N2, $F(1,32)$= 27.29, p<.001, η^2=.18, more so for participants undergoing inhibition training, $F(1,32)$= 5.18, p<.05, η^2=.03. However, the enhancement from training in N2 amplitude in each group was equivalent for congruent and incongruent stimuli (see Figure 9), $F(1,32)$=.10, *ns*, η^2=.0002. Therefore, neither inhibition training nor discrimination training differentially affected the magnitude of the N2 congruity effect to target stimuli.

P3 component. There was a main effect of Training on target P3 amplitude, $F(1,32)$= 6.86, p<.05, η^2=.12, with the magnitude of P3 decreasing from pretest to posttest. However, the training effect was restricted to the inhibition training group, $F(1,32)$= 5.10, p<.05, η^2=.09. There was no effect of Congruity, $F(1,32)$= 1.11, *ns*, η^2=.02. Nevertheless, a significant three-way interaction of Training, Group, and Congruity was found, $F(1,32)$= 15.64, p<.001, η^2=.19. Whereas inhibition training yielded a significant decrease in the amplitude of P3 to incongruent targets, discrimination training slightly increased P3 amplitude to these target stimuli, as shown in Figure 10. Furthermore, ANOVA of P3 amplitude to the first flanker revealed a marginally significant main effect of Congruity, $F(1,32)$= 3.58, p<.07, η^2=.07, with relatively weaker P3 magnitude to incongruent stimuli. The congruity effect in P3 was equal between groups before training, $F(1,32)$= 1.64, *ns*, η^2=.02. There was no main effect of Training, $F(1,32)$= 2.64, *ns*, η^2=.04, but there was a significant interaction between Training and Group, $F(1,32)$= 9.58,

$p<.01$, $\eta^2=.16$: Inhibition training decreased, whereas discrimination training increased, distractor P3 amplitude from pretest to posttest. The distinct effects of inhibition or discrimination training on distractor P3 were mainly relegated to incongruent stimuli, resulting in a significant three-way interaction of Training, Group, and Congruity, $F(1,32)= 5.69$, $p<.05$, $\eta^2=.06$ (see Figure 11).

RP component. The analyses of RP to the first flanker revealed a main effect of Congruity, $F(1,32)= 17.189$, $p<.001$, $\eta^2=.21$, which showed that the magnitude of RP was greater for congruent stimuli, in comparison to the incongruent stimuli. However, the main effect of Training, $F(1,32)= .19$, ns, $\eta^2=.004$ was not significant. Nevertheless, a significant three-way interaction between Congruity x Group x Test, $F(1,32)= 4.87$, $p<.05$, $\eta^2=.06$, showed that in response to incongruent trials, RP magnitude increased after inhibition training but decreased after discrimination training, as displayed in Figure 12. Furthermore, the relationship between RP and the behavioral data (RT and accuracy) was analyzed through linear regressions for the filtering tasks across both training groups, test sessions, and stimulus types. As shown in Figure 13 (left panel), as the magnitude of RP increased, participants' RT decreased (r=-0.74). Similarly, performance in accuracy also improved (r=0.83) as RP magnitude increased (see Figure 13, right panel).

Time-Frequency Analysis

The mixed-model ANOVA was computed on log transformed alpha power for both evoked and induced oscillations. No significant main effects of Group (Discrimination Training and Inhibition Training) or Test (Pretest and Posttest) were found at any electrode site for both evoked and induced alpha oscillations.

Evoked alpha oscillations. Figure 14 depicts log transformed evoked alpha power for both training groups across the two testing periods for all four time epochs across the three recorded sites. There was no main effect of Test, $F(1,34)=.045$, ns, $\eta^2=0.001$, no main effect of Group, $F(1,34)=1.341$, ns, $\eta^2=0.038$, and no interaction between Test and Group, $F(1,34)=0.008$, ns, $\eta^2=0.000$. However, there was a significant main effect of Electrode, $F(2, 68)=6.658$, $p=0.009$, $\eta^2=0.164$. As shown in Figure 15, the log-transformed evoked alpha power decreased after discrimination training but increased after inhibition training at the Pz and POz sites; however, at site Oz, there was an increase in evoked log-transform alpha power after discrimination training but a decrease after inhibition training. Also, there was a significant main effect of Frequency, $F(4, 136)=69.830$, $p<0.001$, $\eta^2=0.673$. As shown in Figure 16, evoked alpha power varied among the different frequencies in the alpha range, with the highest power at 8 Hz and the lowest power at 12 Hz across both training groups, suggesting that the lower alpha-band (8-10 Hz) may be more involved in cognitive processing and distractor suppression, in comparison to the upper alpha band. Additionally, a significant main effect of Time, $F(3, 102)=27.706$, $p<0.001$, $\eta^2=0.449$, was revealed from the analysis, as shown in Figure 17, which indicated the highest alpha power between 100-300 ms during the trial, in comparison to the first and fourth time epochs.

Induced alpha oscillations. Figure 18 portrayed the induced log-transformed alpha power for the two training groups for both pretest and posttest sessions, across the three sites for the full alpha frequency range for all four time epochs. Similar to the evoked alpha power, there was no main effect of Test, $F(1,34)=.533$, ns, $\eta^2=0.015$, no main effect of Group, $F(1,34)=0.389$, ns, $\eta^2=0.011$, and no interaction between Test and Group, $F(1,34)=2.338$, ns, $\eta^2=0.064$. Nevertheless, a significant main effect of Frequency was found, $F(4,136)=75.392$, $p<0.001$,

η^2=0.689, with the lower alpha band significantly higher in power compared to the higher alpha band across both training groups (see Figure 19). Furthermore, the interaction between Test and Frequency was marginally significant, $F(4,136)$=2.868, p=0.096, η^2=0.078, with the drop in alpha power greater in the lower alpha band, significantly so at the 8 Hz frequency as shown in Figure 19, from pretest to posttest when averaged across all participants. Lastly, a two-way interaction between Test x Time was marginally significant, $F(3, 102)$=2.518, p=0.091, η^2=0.069, indicating that the drop in alpha power, from pretest to posttest, was highest at the 201-300 ms epoch followed by the 301-400 ms epoch, in comparison to the decrease in alpha power during the first two time epochs (see Figure 20).

Discussion

This study investigated the implications of cognitive training on behavioral and neural correlates as healthy participants completed three weeks of either discrimination (focusing on target stimuli) or inhibition (ignoring distractor stimuli) training using a modified version of the visual flanker task, a conflict task employing inhibitory control. We computed an ERP waveform analysis and a time-frequency analysis of the alpha band to assess distractor processing. We tested for training effects across both groups to investigate whether the training induced changes were specific to the alpha band or to the broad-band ERP waveforms.

Behavioral Performance

As predicted, participants took longer to respond to neutral trials in the filtering task compared to the baseline task, indicating greater interference in attention in the filtering task (Garner, 1974). Both inhibition and discrimination trainings reduced Garner interference. Compared to discrimination training, inhibition training led to a more significant reduction in

Garner interference, demonstrating an improvement in selective attention. Similarly, a significant reduction in the congruity effect resulted after inhibition training, indicating more efficient resolution of stimulus conflict. These patterns of responses are consistent with the reviewed literature showing that cognitive training improves behavioral performance on trained tasks (Berkman et al., 2014; Millner et al., 2012; Melara et al., 2002; Rueda et al., 2005; Thorell et al., 2009).

Participants in the inhibition training group improved more than participants in the discrimination training group, as evident by the larger reduction in Garner interference and congruity effect. The inhibition training efficiently improved performance by increasing target sensitivity and reducing distractor processing. No prior study investigated the effects of cognitive training while simultaneously employing the two concurrent mechanisms of visual selective attention to determine which training mechanism (target enhancement or distractor suppression) can improve visual selective attention capabilities. Hence, these findings contribute to previous research by demonstrating that cognitive training focusing on distractor suppression (inhibition training) is more efficient in improving conflict resolution, compared to target enhancement (discrimination) training. Participants in the inhibition training group demonstrated better recovery from conflict on subsequent neutral trials, as measured by the level of Garner interference, suggesting that the suppression of conflict in the incongruent trials during the filtering task had a carryover effect on the neutral trials. The reduction of distractor interference and faster decision speeds for incongruent trials at posttest was more evident in the inhibitory training group, indicative of better inhibitory control and interference resolution. We suggest that training aimed at suppressing distractors is more beneficial than training aimed at differentiating

stimuli since participants in the inhibition training group improved more than participants in the discrimination training group.

ERP Waveforms

Analysis of electrophysiological recordings revealed that inhibition training, compared to discrimination training, increased the magnitude of the N2 ERP component in the target for both congruent and incongruent trials. Inhibition training decreased the magnitude of the P3 component in both the target and the distractor for incongruent trials. Moreover, the magnitude of RP increased to distractors for incongruent trials after inhibition training, suggesting an improvement in inhibitory control which was strongly correlated to measures of behavioral performance on the flanker task.

Consistent with Purmann and colleagues' (2011) findings, we observed a larger N2 amplitude in response to incongruent trials than congruent trials. Purmann et al. (2011) reported a decrease in the amplitude difference across different congruities as participants were exposed to frequent conflict. Millner et al. (2012) found that practice on the Simon task reduced the difference in N2 amplitude on the flanker task between congruent and incongruent trials. Our results did not show the same pattern in N2 amplitude. Instead, the magnitude of N2 for targets increased equally for congruent and incongruent trials across both training groups, resulting in no significant interaction between test session (pretest and posttest) and congruity (congruent and incongruent), hence showing no effect of either discrimination or inhibition training on the N2 congruity effect in the flanker task. Millner et al. (2012) used an inhibition training procedure with repeated presentation of equally salient conflict trials, whereas the inhibition training used here gradually increased the distractor magnitude as training progressed, preventing conflict signal habituation. Although the increase in the N2 target magnitude was greater after inhibition

training, the absence of a training effect across congruity suggests that conflict monitoring, as measured by N2 amplitude (van Veen & Carter, 2002), may not be amenable to cognitive training. Nevertheless, inhibition training improved conflict monitoring for both congruent and incongruent stimuli, suggesting better inhibition of distractors regardless of their compatibility to the target stimulus.

Although our results showed no effect of either inhibition or discrimination training across congruity conditions on N2, we observed a decrease in P3 amplitude on targets and distractors for incongruent trials after inhibition training. This pattern of P3 suppression is in line with previous findings by Melara and colleagues (2002), suggesting the activation of an inhibitory control network, which reduces the P3 amplitude, indicating distractor suppression. We suspect that the inhibition training gradually reduced distractor salience, hence producing a weaker P3 waveform after training. In contrast, discrimination training produced higher P3 amplitudes after training, reflecting active target processing. Previous findings by Melara and colleagues (2002, 2012) reported P3 suppression from inhibition training across all trial types; however, we only observed P3 suppression for incongruent trials across both target and distractor processings after inhibition training. This finding suggests that inhibition training was more efficient in reducing the perceived salience of conflicting stimuli, as presented in incongruent trials where the target is flanked by mismatched distracters. The suppression of the P3 waveform for the inhibition training group, coupled with the improvements in behavioral performance at post-test, reveals the training induced suppression of the interfering distractors for incongruent trials. The training provides repeated practice of distractor suppression which reduces sensitivity to the distractor, resulting in less distractor interference in performance at post-test.

Consequently, inhibition training is more effective in reducing interference caused by conflicting stimuli, hence improving inhibitory control.

Melara and colleagues (2002) reported improvements in auditory selective attention after inhibition training that are linked to an enhanced RP waveform to the distractor. Similarly, we implemented an inhibition training using a visual conflict flanker task in which participants were trained to suppress distractor processing and improve inhibitory control. We found an enhanced RP waveform to the distractor, specifically for incongruent trials at the posttest for inhibition training, indicating better inhibitory control. The RP waveform for incongruent trials reduced after discrimination training, where participants were trained to improve target discrimination. These findings allowed us to deduce that enhancements in RP are dependent on the form of training because they are linked to distractor processing. Enhancement in RP is also strongly related to behavioral performance, as evident from the correlational analyses between RP and RT/accuracy. These results contribute to the literature, extending Miller and colleagues' findings by demonstrating that a conflict flanker task used in inhibition training induces neural changes that are specific to incongruent distractors, as evident by the enhanced RP and suppressed P3. Moreover, by computing a separate analysis of target and distractor processing in the flanker task, we have shown that the component of distractor suppression of selective attention is amenable to training in both the auditory (Melara et al., 2002; 2012) and the visual modalities.

Time-Frequency Analysis

Despite the prevalence of significant training effects across inhibition and discrimination training in the ERP waveforms for incongruent trials, these effects were not found in either evoked or induced alpha-band rhythms. Precautions were taken to make sure that the analyses and paradigm were sensitive to training effects. For example, the alpha power was normalized

using logarithmic transformation and computed separately for both training groups across

multiple electrode regions for individual frequencies within the alpha band across pre-defined

time epochs. Each participants served as their own control since their training was coupled with a

pre- and posttest session. Despite our best efforts to find training effects between groups, the null

findings contribute to the literature by suggesting that the alpha band may not be amenable to

inhibitory control training using a visual conflict task.

Nevertheless, we found the lower alpha band to be higher in power for both evoked and

induced alpha rhythms, as compared to the higher alpha band. As discussed, the lower alpha

band is associated with alertness and encoding of new information (Doppelmayr et al., 2002,

2005; Klimesch et al., 2000). We used a visual conflict flanker task employing inhibitory control

which required the participant to stay alert and maintain focus on the target stimulus, hence

producing higher amplitudes of the lower alpha band, compared to the higher alpha band during

both testing sessions.

Interestingly, our results revealed a marginal significance for log-transformed induced

alpha power across testing sessions for frequency and time epoch. There was a large drop in

induced alpha power from pretest to posttest for frequencies 8 and 9 Hz. Moreover, the decrease

in alpha power from pretest to posttest was higher at the 201-300 and 301-400 ms time epochs,

compared to the earlier time epochs. The possible interaction between test and time epoch as

well as test and frequency suggests that there was a tendency for a training effect, although it was

not group specific. The three weeks of cognitive training (both discrimination and inhibition

training) led to a reduction in the alpha power, suggesting an improvement in target processing.

Prior studies have linked alpha ERD to target processing and target enhancement (Kelly et al.,

2006; Klimesch et al., 2007; Snyder & Foxe, 2010; Vanni et al., 1997). Hence, a decrease in

alpha power indicates better target processing, suggesting that from the two mechanisms of selective attention, the alpha band reflects training of target enhancement, but not distractor suppression. However, we did not observe any group differences as a result of training, which prompts further investigation of the role played by the alpha band rhythm in attentional processing as well as their capacity for training. This study contributes to previous research by re-demonstrating that the lower alpha band is associated with task induced arousal (Doppelmayr et al., 2005; Klimesch et al., 2000) and displays training effects of reduced alpha power, suggesting target enhancement (Kelly et al., 2006; Klimesch et al., 2007; Snyder & Foxe, 2010; Vanni et al., 1997).

Limitations and Future Directions

Despite the abundance of studies reporting behavioral and electrophysiological changes after discrimination training, the current study did not find significant changes in performance to either target or distractor as a result of discrimination training (Atienza, Cantero, & Dominguez-Marin, 2002; Tremblay, Kraus, Carrell, & McGee, 1997). A possible explanation is that repeated practice in target discrimination with neutral flankers in our paradigm was ineffective in improving discrimination skills. To overcome this limitation, the training paradigm should gradually increase task difficulty by making the target stimuli harder to discriminate, as demonstrated by another training study conducted by Tong, Melara, and Rao (2009).

This study did not measure individual differences when analyzing changes in alpha band power. As discussed in the introduction, studies found differences in alpha power when factoring in intelligence (Doppelmayr, Klimesch, Stadler, Pöllhuber, Heine, 2002), performance (Klimesch, 1997; Klimesch, Schimke, Doppelmayr, Ripper, Schwaiger, & Pfurtscheller, 1996), and level of education (Begum, Reza, Ahmed, Elaina & Abdullah, 2011). It is possible that

discrimination and inhibition training effects are dependent on individual differences, therefore, conducting a separate analysis across "good" and "bad" performers would have accounted for individual differences and may have demonstrated group differences across training groups.

Lastly, to our knowledge, this was the first training study to measure alpha band rhythms as a function of cognitive training using a visual flanker task. Although significant training effects were not found in the alpha band, ERP analysis revealed significant training effects to the distractor in the P3 and RP waveforms. Despite the null findings of the time-frequency analysis, this study paves the way for analyzing frequency-specific bands in cognitive training paradigms to attain a more enhanced viewpoint of the neural mechanisms underlying cognitive functioning.

Conclusion

Thirty-six participants were randomly assigned to three consecutive weeks of either discrimination training (target discrimination) or inhibition training (distractor inhibition), coupled with a pre- and post-training testing session. The trainings and testing sessions used a modified version of the Eriksen flanker task, a visual conflict task using inhibitory control. The behavioral results revealed that the ability to suppress incongruent distractor stimuli, a crucial component of selective attention, improved more after inhibition training, as compared to discrimination training. For example, Garner interference, measuring selective attention, and Stroop interference, measuring conflict resolution, reduced after inhibition training. Moreover, the ERP analysis revealed a reduction in the P3 waveform in response to the distractor after inhibition training, indicating better distractor suppression. Meanwhile, an increase in the RP component to the distractor after inhibition training revealed better inhibitory control. The time-frequency analysis of the evoked and induced alpha-band rhythms revealed no significant group differences, however, exhaustive probing revealed a tendency for a training effect that was not

group specific. Nevertheless, we suggest further investigation of the role of the alpha band and

accounting for individual differences in cognitive training and selective attention mechanisms.

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Appendix

Figure 1: EEG averaging across multiple trials to generate an ERP waveform
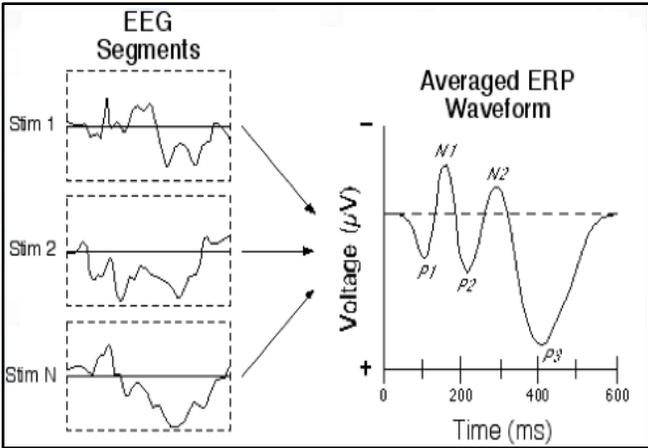
Figure 2: Spectrogram (x-axis: Time; y-axis: Frequency)
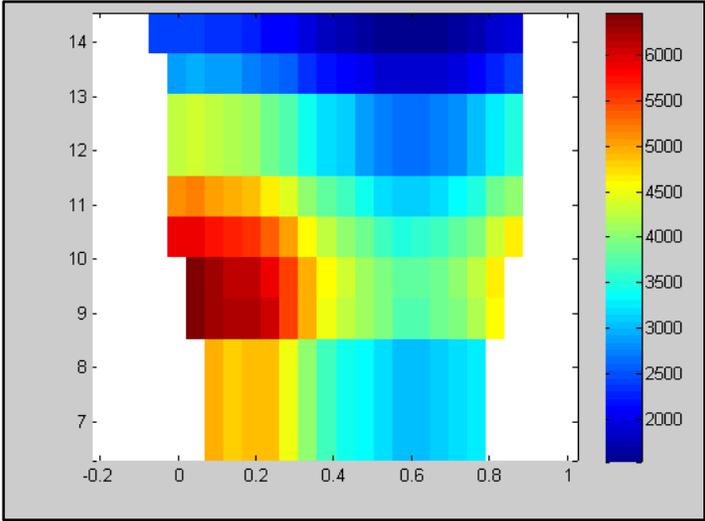
Figure 3: Morlet wavelet
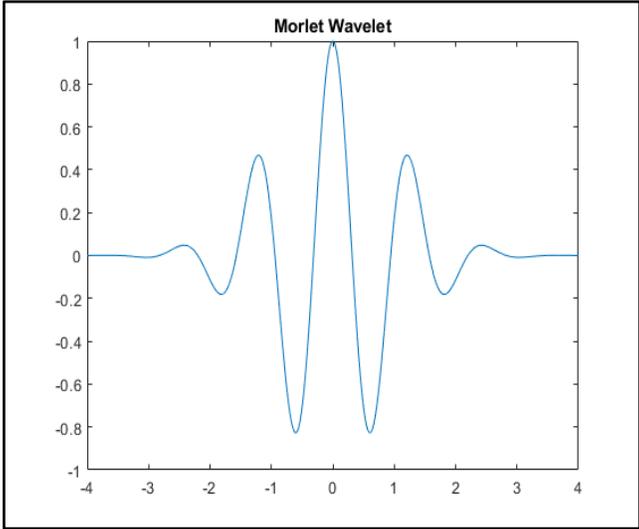
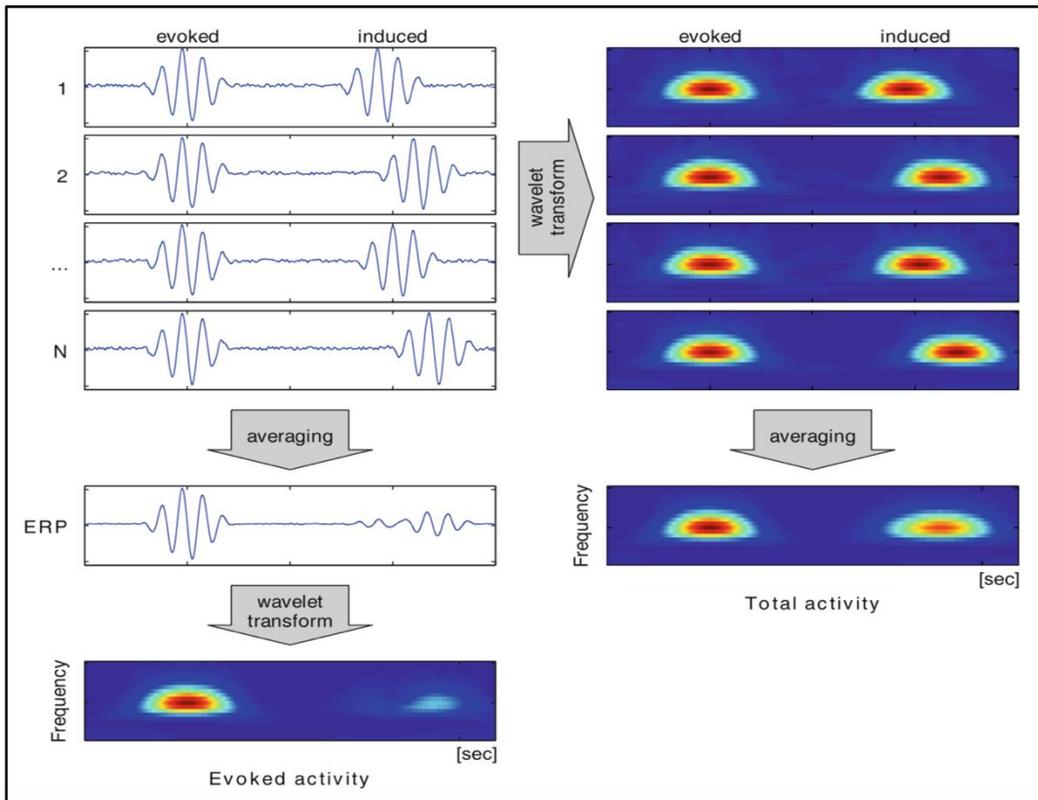Figure 4: Induced and evoked activity extraction (Adapted from Hermann et al., 2014)
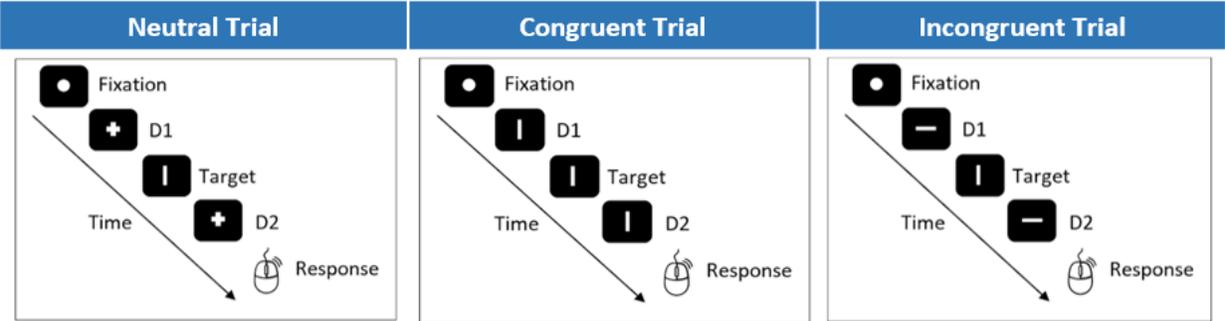
Figure 5: Temporal Flanker Task

Figure 6: Procedure Outline

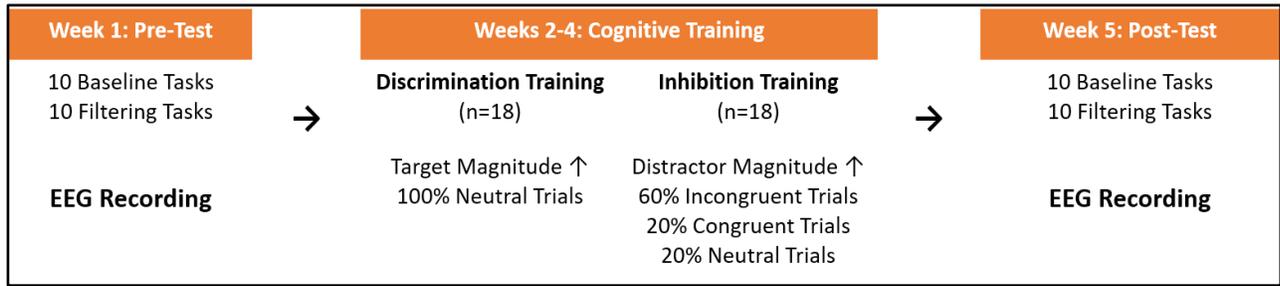| Week 1: Pre-Test	Weeks 2-4: Cognitive Training		Week 5: Post-Test
10 Baseline Tasks 10 Filtering Tasks	**Discrimination Training** (n=18)	**Inhibition Training** (n=18)	10 Baseline Tasks 10 Filtering Tasks
EEG Recording	Target Magnitude ↑ 100% Neutral Trials	Distractor Magnitude ↑ 60% Incongruent Trials 20% Congruent Trials 20% Neutral Trials	**EEG Recording**

Table 1: Sample Demographics

	Total	Discrimination Training	Inhibition Training
Participants	36	18	18
Age Mean (SD)	20.36 (2.66)	20.50 (3.01)	20.22 (2.34)
Females	25 (69.44%)	13 (52%)	12 (48%)
Males	11 (30.56%)	5 (45.45%)	6 (54.55%)
White	9 (25%)	5 (55.56%)	4 (45.44%)
Asian	7 (19.44%)	4 (57.14%)	3 (42.86%)
Black/African American	3 (8.33%)	1 (33.33%)	2 (66.67%)
Hispanic or Latino	17 (47.22%)	8 (47.06%)	9 (52.94%)
High School Students	11 (30.56%)	6 (54.55%)	5 (45.45%)
College Students	20 (55.56%)	9 (45%)	11 (55%)
College Graduates	4 (11.11%)	2 (50%)	2 (50%)
Graduate Students	1 (2.78%)	1 (100%)	0 (0%)

Table 2: Behavioral Data

	Pre-test				Post-test			
	Discrimination Training							
Task	*RT (ms)*	*SE*	*Accuracy (%)*	*SE*	*RT (ms)*	*SE*	*Accuracy (%)*	*SE*
Baseline	455	11.88	95	1.26	420	9.73	97	0.58
Neutral	491	14.77	95	1.33	441	10.66	96	0.60
Congruent	414	14.63	98	0.48	386	11.41	98	0.40
Incongruent	610	30.51	76	3.39	555	28.74	85	2.76
	Inhibition Training							
Task	*RT (ms)*	*SE*	*Accuracy (%)*	*SE*	*RT (ms)*	*SE*	*Accuracy (%)*	*SE*
Baseline	474	14.80	97	0.67	444	13.09	97	0.59
Neutral	514	20.11	96	0.58	445	12.50	97	0.57
Congruent	445	19.76	98	0.48	417	13.38	98	0.41
Incongruent	713	45.53	66	4.14	587	38.14	79	4.50

Figure 7: Garner Interference
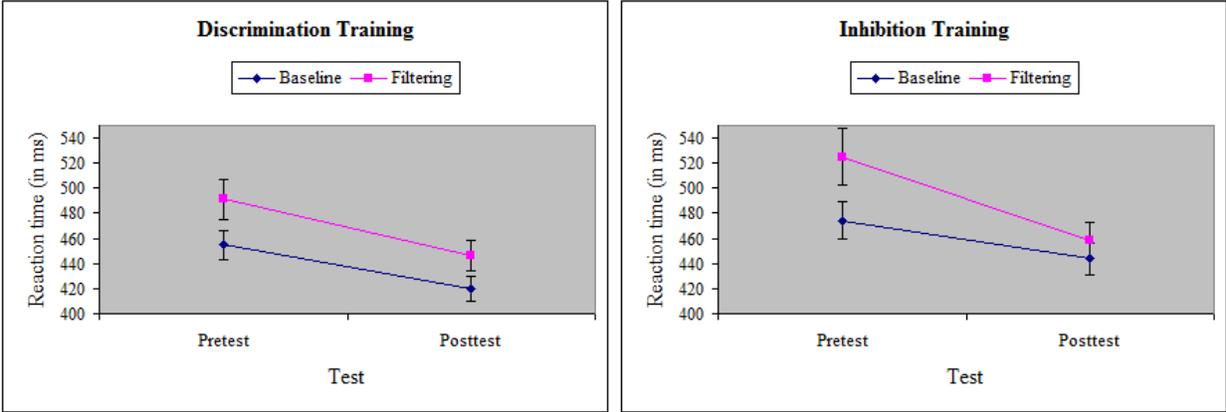
Figure 8: Congruity Effect
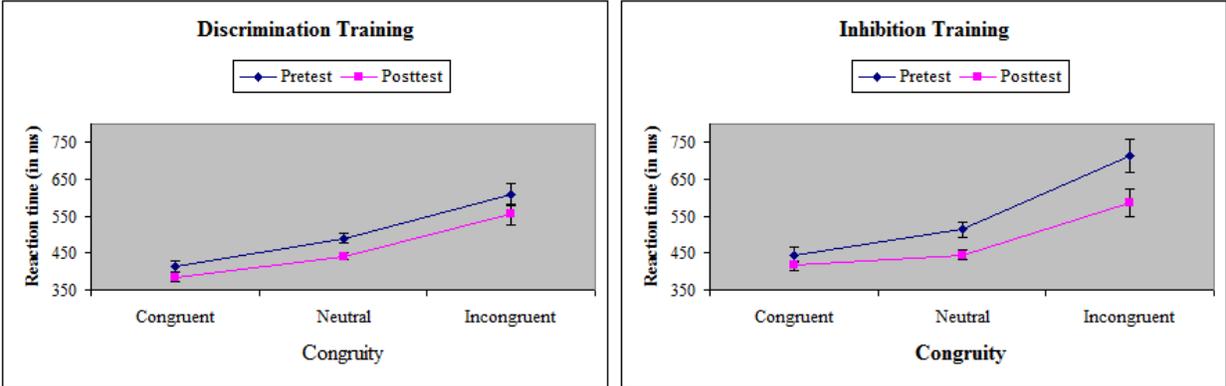
Figure 9: Target N2 Amplitude
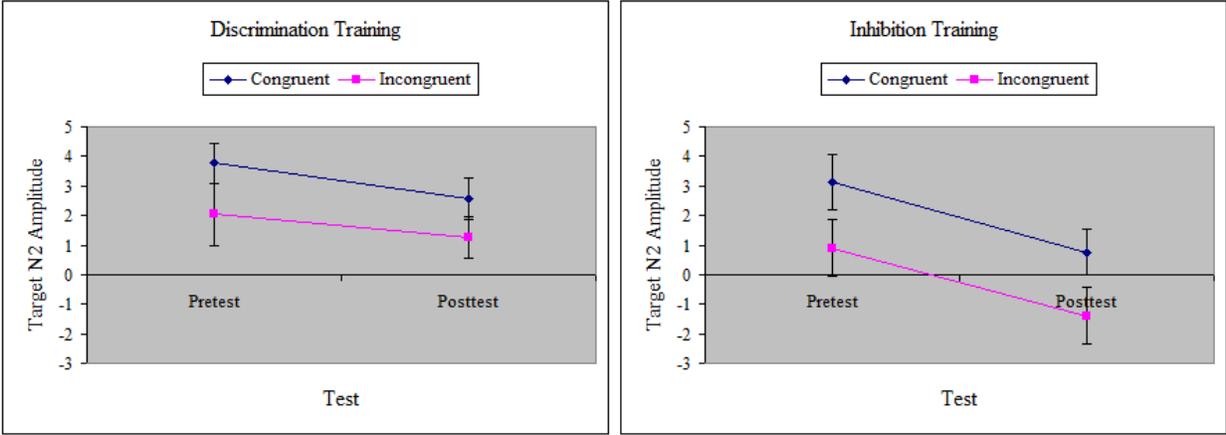
Figure 10: Target P3 Amplitude
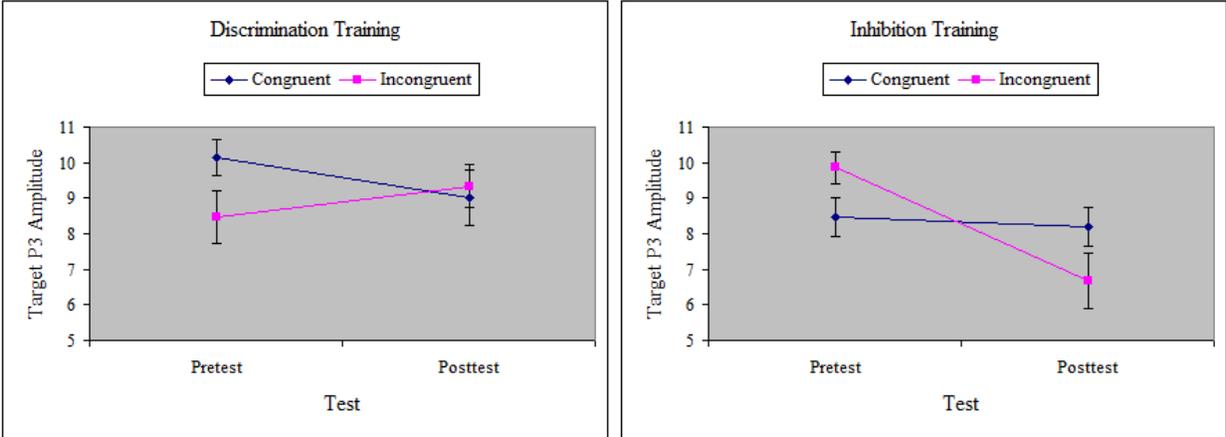
Figure 11: Distractor P3 Amplitude
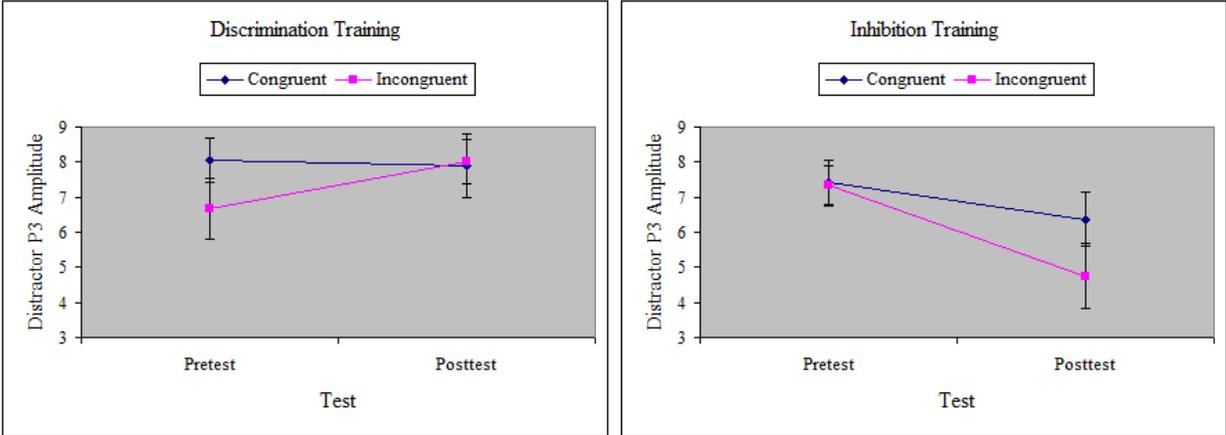
Figure 12: Distractor RP Amplitude
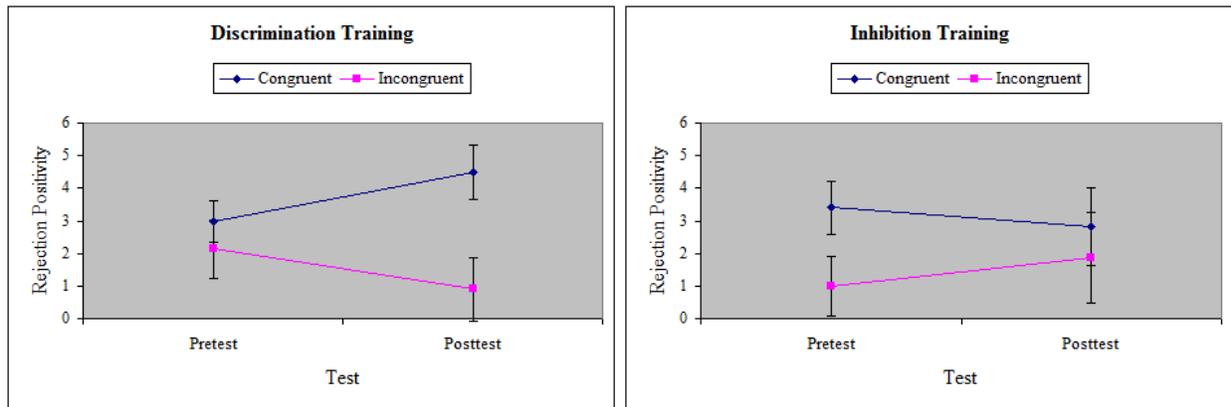
Figure 13: Distractor RP Regression
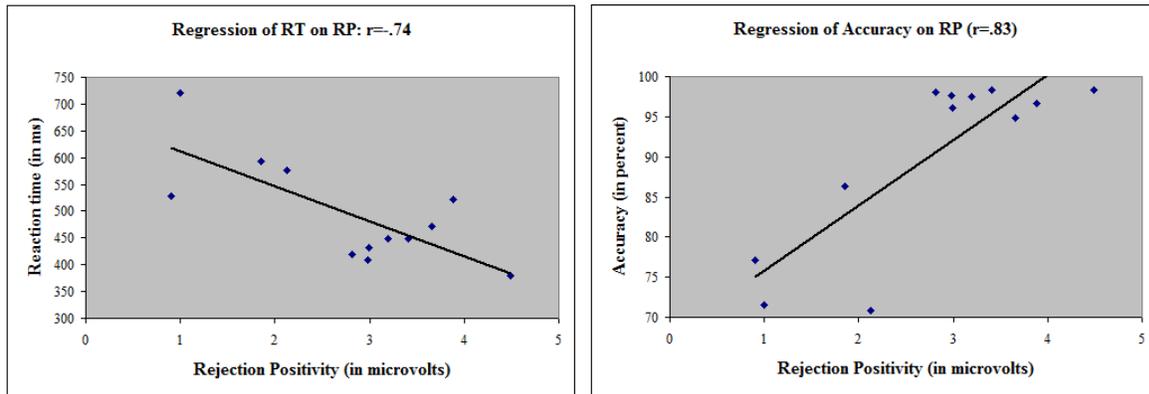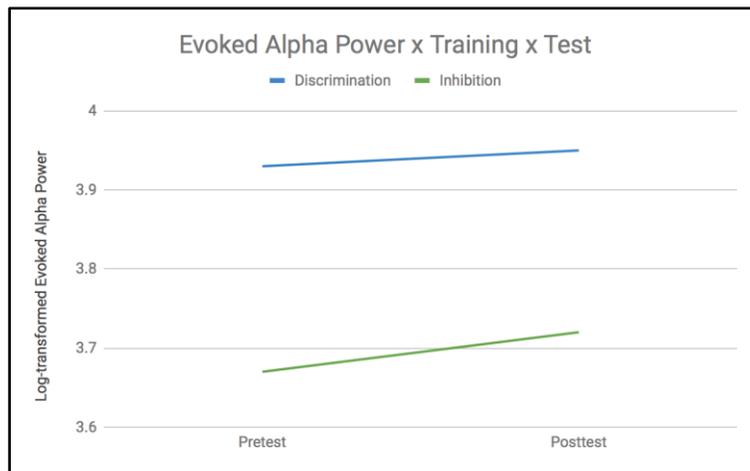
Figure 14: Post-log Evoked Alpha Power

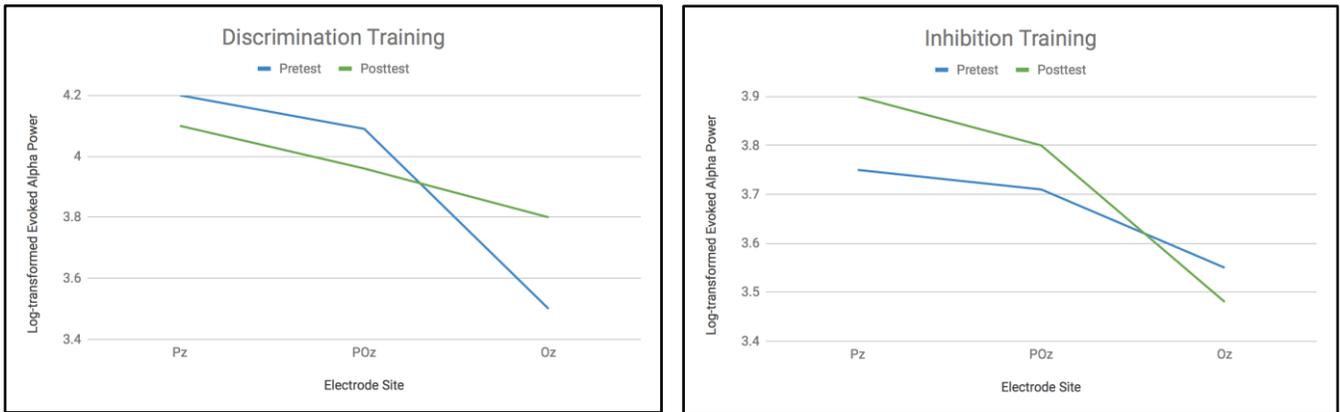Figure 15: Post-log Evoked Alpha Power across Electrode Sites

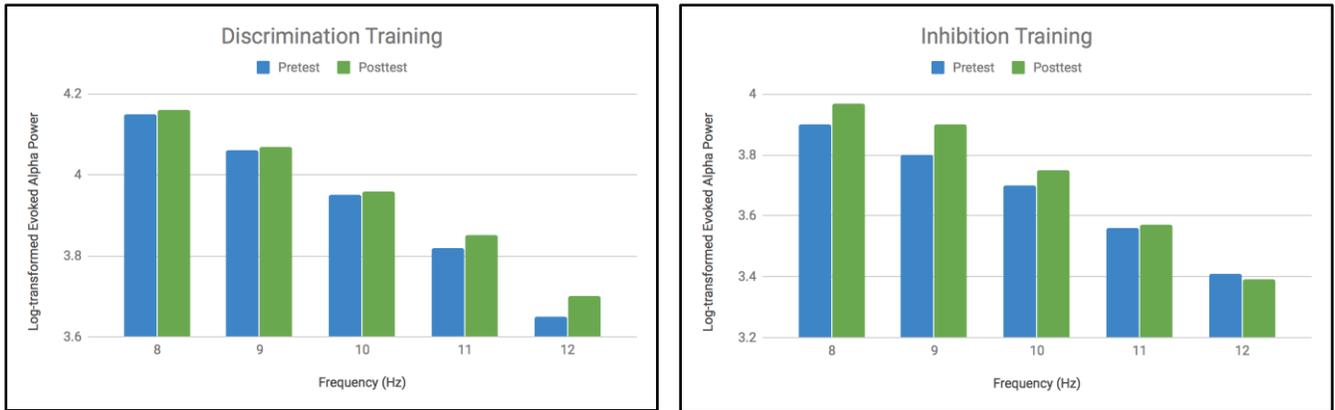Figure 16: Post-log Evoked Alpha Power by Frequency

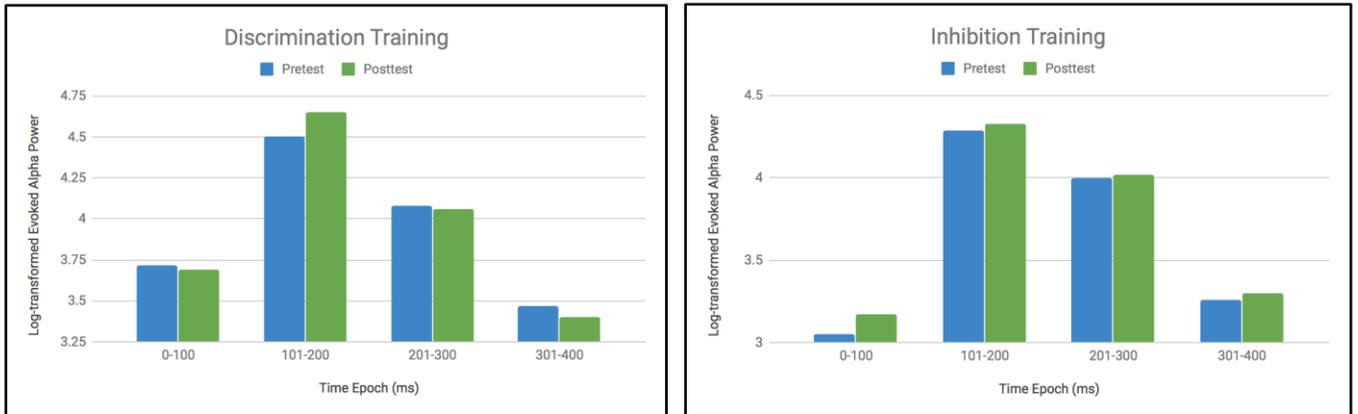Figure 17: Post-log Evoked Alpha Power by Time Epoch

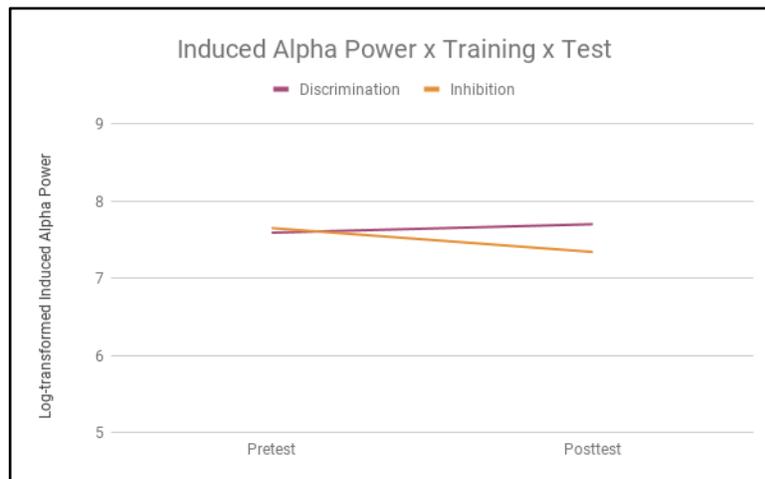Figure 18: Post-log Induced Alpha Power
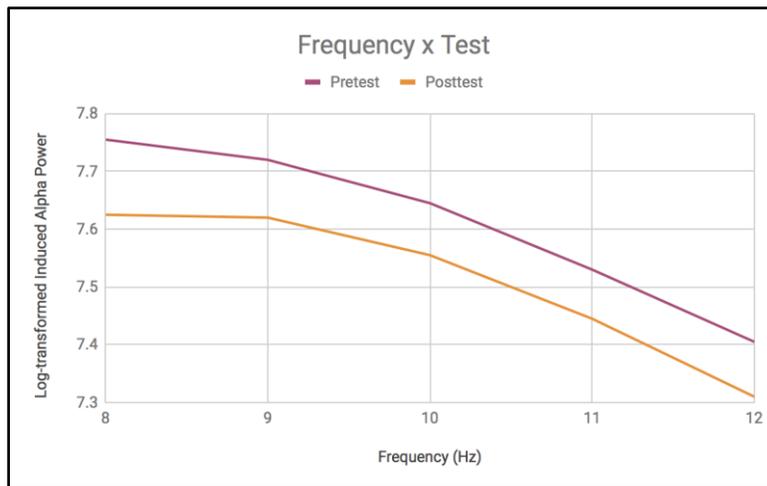
Figure 19: Post-log Induced Alpha Power by Frequency by Test

Figure 20: Post-log Induced Alpha Power by Time by Test