The impact of Cognitive Training on Brain Electrophysiology and Divided Attention in Healthy Older Adults

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Abstract

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Aging impacts older adults' ability to divide their attention. Research has shown that cognitive training techniques are promising in improving divided attention. Investigating the effects of training on electrophysiological brain activity might elucidate the mechanisms underlying improvements and allow better training method selection. Electroencephalography (EEG) is ideal for studying divided attention as switching attention is a dynamic process that takes place within milliseconds and requires high temporal resolution.

All participants (mean age 69.5 years, SD=6.42) performed a visual detection task and an alphanumeric equation task under single and dual-task conditions. Afterwards, participants were randomly assigned to three groups: The single task training group (STT, N=13) practiced the two tasks separately; the fixed attention training group (FAT, N=12) was trained to assign equal attention to both tasks concurrently; the variable-attention training group (VAT, N=14) was trained to flexibly vary their attention while performing the tasks concurrently. After training, participants were tested again. EEG measures were taken pre- and post-training. Training led to behavioural improvements in all of our participants, with the VAT group displaying the greatest benefits and a reduction in dual-task costs. The N1 component was less pronounced after training while P2 was enhanced, suggesting more efficient processing. Functional connectivity measures indicated an increase in theta band coherence between fronto-parietal and fronto-occipital regions in the VAT group, suggesting improved cognitive control. Our results suggest that variable attentional allocation training incurred behavioural benefits with an electrophysiological profile distinct from single task practice and equal priority dual-task training.

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Contribution of Authors

Faisal Al-Yawer: Data analysis, manuscript preparation, manuscript revision.

Natalie A. Phillips: Manuscript preparation, manuscript feedback and revision.

Sylvie Belleville: Project conceptualization and design, participant recruitment and data collection, data analysis feedback.

Samira Mellah: Participant recruitment and data collection, data analysis feedback.

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Table of Contents

List of Tables

List of Figures

Introduction

As we age, a general decline is observed in many of our cognitive abilities such as memory, attention, and executive functions (cf. Park & Schwarz, 2000; Glisky, 2007). One of the abilities impacted by aging is divided attention, an indicator of attentional control abilities. Cognitive training paradigms have been shown to be successful in improving older adults' performance on cognitive tasks, including divided attention tasks (Anguera et al., 2013; Rebok et al., 2014). Divided attention cognitive training is particularly effective when participants are taught a flexible attentional allocation strategy (Kramer et al., 1995; Hertzog et al., 2008). The cognitive processing underlying these behavioural changes in attention is not currently well-understood. The use of a neuroimaging technique with a high temporal resolution such as electroencephalography (EEG) would allow us to capture many of the dynamic changes that occur during the process of dividing attention between two tasks. Thus, in the current study, older adults were trained to flexibly vary their attention while performing a dual-task. EEG data were collected before and after cognitive training and EEG event-related potentials (ERPs) and coherence were examined in order to gain a better understanding of the neurophysiological impact of training. Gaining a better understanding of the underlying neurophysiological correlates of training would help improve future protocols and potentially improve older adults' quality of life. In the following sections we will detail how aging impacts older adults' brains and behaviour; divided attention, how it is measured and how it is impacted by aging; divided attention cognitive training and factors that impact its effectiveness; Neuroimaging and neurophysiological correlates of attention and aging.

Aging

Many different, and at times complementary, theories have been postulated to account for the cognitive decline observed in older adults. Briefly, the speed view postulates that as they age, older adults display a reduction in their processing speed, which then contributes to poorer performance on a given task (Salthouse, 1996; Rypma and D'Esposito, 2000). The resources view, on the other hand, operates under the assumption that for a cognitive process to occur, sufficient attentional resources need to be recruited that vary depending on the complexity of the task (Craik & Byrd, 1982; Reuter-Lorenz et al., 1999). Thus, in older adults, fewer resources are available for task recruitment, leading to difficulties in performance. The inhibition view is based on the notion that age-related cognitive decline results from the inability to inhibit irrelevant information, leading to a confusion of the oncoming message (Hasher & Zacks, 1988).

While the aforementioned theories give plausible interpretations for age-related changes, they do not give an explicit account of physiological brain changes in response to aging. More recently, researchers have suggested that older adults' brains display a level of compensation in response to age-related deterioration. This "functional compensation" is supported by studies showing different patterns of brain activity in older versus younger adults beyond the expected general decrease in activation. Cabeza and colleagues (1997) found that older adults' performance on a verbal memory task differed from young adults in two major ways: First, a general decrease in activity that is seen mainly in left prefrontal and temporo-occipital regions during encoding and in right prefrontal regions during retrieval. Second, they observed a bilateral increase in older adults' brain activity, for example in the left prefrontal cortex during retrieval (Cabeza et al., 1997). This, they suggested, possibly reflects a compensatory mechanism of bilateral activation in the prefrontal cortex to account for the age-related neurocognitive deficits seen in the right prefrontal cortex. Similar effects have also been observed in other tasks, such as face recognition (Grady et al., 2002), and working memory tasks (n-back task, Dixit et al., 2000). This bilateral compensatory activation has been the basis of some modern models of cognitive aging, such as the hemispheric asymmetry reduction in older adults (HAROLD; Cabeza, 2002) model. Other models, such as the Compensation-Related Utilization of Neural Circuits Hypothesis (CRUNCH; Reuter-Lorenz & Lustig, 2005) postulate that advanced age is associated with increased activation and neuronal recruitment in older adults that is not necessarily bilateral. While these views vary in how they conceptualize the changes in the brain in response to age-related decline, they concur that functional changes do occur at a later age which clearly differentiate older from younger adults. How the brain is changed by aging and whether this change is suggestive of deficits or compensatory actions remains the subject of debate.

Divided Attention

Older adults typically experience mild decline in cognitive tasks of attention, memory, and executive functions, among others (cf. Park & Schwarz, 2000). One area of decline is divided attention, which refers to the ability to split attention between two or more tasks. An example would be driving (controlling the steering wheel, paying attention to vehicles and pedestrians) while carrying out a conversation with a passenger. Divided attention is a complex, dynamic process that is not constricted to one brain region, but is instead mediated by a network of connected regions, such as the lateral prefrontal cortex, anterior cingulate cortex, and parietal regions (cf. Marios & Ivanoff, 2005). The ability to successfully divide attention is an indicator of attentional control, which has been found to be adversely impacted by aging (Reuter-Lorenz et al., 1999; Verhaeghen et al., 2003). Studies often try to model divided attention conditions using dual-task paradigms, experiments in which participants are required to perform more than one task at the same time. This seems to at least partially reflect real life performance, as Ball and Owsley (1999) found that older adults' performance on dual-task paradigms partially predicted their rate of automobile accidents. Streyer and Drews (2004) also demonstrated the increased risk of traffic accidents when older adults combined a driving simulator with a cell phone conversation.

The study of dual-task performance in older adults is of great interest to the aging literature as it would help shed light on the nature of functional decline in older adults' attentional control abilities and how that relates to everyday activities, which often involve a multi-tasking or divided attention component. While dual-task studies have been done with many different types and variations of tasks (see Verhaeghen et al., 2003), a typical dual-task paradigm involves two tasks that vary based on three main properties: The underlying cognitive function being examined (for example, working memory or language), stimulus modality (how the task is presented, usually visual or auditory), and response modality (how the participant responds, usually a motor or vocal response). The main dependant variables in divided attention studies are reaction time (RT) and accuracy (Acc). A dual-task "cost" value is sometimes computed using one or both of these variables.

A variation on the common dual-task paradigm is referred to as the psychological refractory period (PRP) task. In a typical PRP task, one task appears first, followed rapidly by a second task that is presented at various times (can range from 50 to 500 ms after the initial task). Variations of the time interval between the two tasks, known as stimulus onset asynchrony

(SOA), help elucidate the processing demands involved in dual-task performance (Pashler, 1998). The main finding from classical PRP experiments is that reaction time on the second task increases as the SOA is decreased. In general, aging studies tend to compare performance between younger and older adults, in addition to performance between single- and dual-tasks. PRP paradigms compare performance on conditions with small SOAs (an SOA of 0 ms indicates that both tasks occur at the same time) to larger SOAs.

Several issues require consideration when examining divided attention in older adults. First, many studies do not employ proper controls by comparing performance on dual-tasks to performance on single tasks performed individually. Second, the method in which dual-task cost is calculated varies between studies. For example, some studies compute the dual-task cost using a difference approach between single and dual-task performance (e.g., Kramer et al., 1995; Cost = [Single Task 1 RT + Single Task 2 RT] – Dual-task RT). Other studies use a ratio approach to determine cost (e.g., Bier et al., 2014; Cost = Dual-task RT – [Single Task 1 + 2 RTs] / [Single Task 1 +2 RTs]). The use of a ratio is generally more useful as it presents cost as a proportion of single task performance, as opposed to an absolute value. Studies also differ in the number of variables they use, as most studies use only RT to calculate cost (eg., Rogers et al., 1994) while others include both RT and Acc in their calculations (eg., Bier et al., 2014). The advantage of including both Acc and RT in dual-cost calculations is that it accounts for any speed-accuracy trade-offs.

Another issue worth considering is the types of tasks being combined to form the dual task. As expected, variations in the types and complexity of tasks used between different studies can engender different effects. During concurrent performance of two memory tasks, for example, older adults showed significant dual-task impairments relative to younger adults (Salthouse et al., 1984). When performing visual discrimination tasks or tracking tasks simultaneously, older adults' dual-task performance was equivalent to younger adults (Somberg & Salthouse, 1982; Hahn & Kramer, 1995), but not when the complexity or the duration of tasks were increased (Sekuler et al., 2008; Trick et al., 2005). The "tasks" involved in a dual-task do not necessarily have to be cognitive, as research has shown that even motor and gait control can interfere with task performance (for a review see Woollacott & Shumway-cook, 2002). For example, a recent study by Malcom and associates (2015) has shown a decrease in older adults' performance on a Go/No-Go inhibition task while walking on a treadmill compared to stationary sitting, which was also associated with electrophysiological changes on the EEG. Modality also plays a great role in modulating dual-task performance differences. Tasks that share the same modality (intramodality tasks), such as two visual tasks, tend to have larger costs than tasks that employ different modalities (intermodality tasks), such as a visual paired with an auditory or tactile task (Pashler, 1998; Wahn & König, 2016). This is likely because simultaneous or parallel processing of highly similar tasks interferes, or has the potential to interfere, with one another, a phenomenon known as "cross-talk". This leads to slower or less accurate responses (Pashler, 1998; Navon & Miller, 1987). Dual-task performance in older adults might also be dependant on the stage of processing, as Wild-wall and colleagues (2011) found increased dual-task costs on a visual discrimination task during the retention period of a working memory task but not during retrieval. Clearly, dual-task performance is highly dependant on a number of nuanced factors.

In a comprehensive meta-analysis, Verhaeghen and colleagues (2003) examined 33 studies of dual-task performance in older adults, looking independently at how Acc and RT on these tasks are impacted by aging. Looking at RT (latency) differences, they found that conducting a dual-task added an extra step to the processing of the single tasks regardless of age. Furthermore, older adults are slower than younger adults at performing dual-tasks beyond what would be expected from general age-related slowing, indicating a specific deficit in the ability to divide attention in aging (Verhaeghen et al., 2003). Conversely, the meta-analysis' findings regarding dual-task accuracy indicated that older adults' increase in accuracy costs was not beyond what would be expected from age-related decline. In other words, the results indicated that older adults show a significant deficit in the speed of processing of dual-tasks but not necessarily in their accuracy of responding to said tasks. While the meta-analysis found no impact of mediating factors, such as task complexity, on outcome measures, it is still important to consider that the studies examined employed a large variety of tasks, from auditory cue recognition to visual search to digit substitution to short- and long-term memory tasks, making the sample highly heterogeneous (Verhaeghen et al., 2003). One factor that might contribute to the specific dual-cost deficits seen in older adults is response strategy. Glass and associates (2000) showed that in addition to generalized slowing, older adults also tended to use more cautious task-coordination strategies while performing a PRP task, leading to poorer performance compared to younger adults. Thus, the findings seem to point towards a specific processing cost of divided attention in older adults beyond general slowing, which might be partially related to a reliance on attentional control strategies. Therefore, the question arises about whether these deficits can be targeted and improved.

Cognitive Training

Cognitive training has been proposed as a method to optimize cognitive functioning in healthy older adults as a possible preventative measure against age-related cognitive decline

(Belleville, 2007). Researchers have used a variety of cognitive training methodologies in order to improve various cognitive functions, from processing speed (Ball et al., 2007), fluid intelligence (Jaeggi et al., 2008), job performance (Lampit et al., 2014), to attentional control (Bherer et al., 2006; Kramer et al., 1995). While the findings are mixed, skills obtained with cognitive training have been retained for a number of years (e.g., Rebok et al., 2014) and shown transfer to untrained skills under certain conditions (e.g., Kramer et al., 1995; Roenker et al., 2003). Many factors contribute to the success or failure of a cognitive training interventions, such as the length and intensity of training (see Papp et al., 2009 and Reijnders et al., 2013, for recent critiques). Nonetheless, several researchers have argued that a successful cognitive training study focuses on training cognitive processing mechanisms (metacognitions) as opposed to learning individual skills (Hertzog et al., 2008).

Cognitive training studies of divided attention seem to support this notion. Kramer, Larish, and Strayer (1995) distinguished between two types of dual-task training: part-task and whole-task training. Part-task training involves practicing and becoming proficient at individual tasks separately. It reduces processing demands and allows for automaticity; however, it does not develop attentional allocation abilities nor does it account for the skills required to perform tasks simultaneously (Kramer et al., 1995). In contrast, whole-task training involves practicing performing tasks together. It allows for the development of attentional allocation and organizational strategies, yet it involves higher processing costs than the part-task training. Interestingly, a PRP study by Oberauer and Kliegl (2004) demonstrated that training on two tasks individually (that is, part-task training) did not significantly reduce costs when doing the two tasks simultaneously, while dual-task training led to a cost reduction, almost achieving perfect parallel processing (that is, having RTs on the dual-task that are equal to the sum of the

RTs of the two single tasks). The authors suggested that automatization via part-task training does not lead to a noticeable reduction in dual-task costs (Oberauer and Kliegl, 2004; Nino & Rikard, 2003).

Other studies have shown that dual-task training is optimized when it is paired with adaptive participant feedback during training. For example, Hazeltine and colleagues (2002) trained participants on a visual detection task (requiring a motor response) combined with an auditory discrimination task (requiring a vocal response). Adaptive feedback was provided to the participants during training in the form of target RTs that were calculated based on their single task performance. Their findings showed a large dual-task cost reduction that was maintained even when new visual and auditory stimuli were used, consistent with previous studies (Schumacher et al., 2001). The authors suggest that training allowed for parallel processing of both tasks, leading to reduced costs (Hazeltine et al., 2002). A study by Maquestiaux and associates (2004) using the same dual-task modalities, visual and auditory, found little benefit for dual-task training.; One of the factors dissociating the Maquestiaux study from the other studies was that, unlike the other studies, participants did not receive feedback during training and instead were only allowed to practice the dual-task. However, it is important to note that other methodological factors might have contributed to the differences between the two studies. For example, the length of training varied as participants in the Hazeltine study trained for two weeks while those in the Maquestiaux study took part in practice over the span of four days (Hazeltine et al., 2002; Maquestiaux et al., 2004). Nonetheless, performance feedback has been proposed as an essential component of efficient learning as it allows precise adjustments on the part of the learner and makes the learnt information more tangible and immediate (Schmidt & Bjork, 1992).

A classic study by Kramer and colleagues (1995) demonstrated that the type of dual-task training also played a role. They trained individuals to perform a dual-attention task consisting of a complex monitoring task (monitoring six gauges and resetting ones that reach a critical point) and an alphanumeric task (mentally computing the answer to an equation such as “D -3 = ?” and then comparing the answer to the previous trial). Two training groups were created: A fixed-priority training group, trained to give equal amounts of attention to the two tasks; and a variable-priority training group which was trained to vary their attentional allocation based on task instructions (Kramer et al., 1995). Both groups were given feedback during training to allow them to reach the desired levels of performance. The findings from this study demonstrated a clear advantage for the variable-priority training group compared to fixed-priority training as evidenced by the improved reaction times for that group by the end of training. Furthermore, transfer to a working memory task was also evident for the variable training compared to the fixed attentional training group (Kramer et al., 1995). Similar benefits for variable allocation were observed in studies were participants were trained to switch between focusing on speed and accuracy during a dual-task (Gopher et al., 2000).

Another cognitive training intervention that emphasized flexible attentional allocation comes from Bherer and colleagues (2005). In that study, participants (young and older adults) underwent inter-modality dual-task training with adaptive feedback. Participants had to respond to different auditory tones by pressing certain buttons with one hand, while also responding to the visual presentation of a letter by pressing a button with their other hand (Bherer et al., 2005, 2008). Their findings, contrary to those of Kramer and colleagues (1995, 1999), did not indicate a difference between the fixed and variable training groups, though both showed reduced costs relative to untrained controls. Bherer and associates postulated that these discrepancies could stem from the use of different modalities (intermodality), that being auditory and visual, in their experimental design, while the two tasks in the Kramer study were both visual. The researchers suggested that the use of different modalities might have made the dual-task easier for the participants: As previously discussed, intermodality dual-tasks tend to have lower costs than intramodality tasks, thus it is possible that the participants did not face enough difficulty with the tasks to rely on cognitive control strategies (Bherer et al., 2005, 2008). While these findings suggest that flexible attentional training can potentially improve cognitive control in older adults, the mechanism by which this improvement occurs in the brain is largely unknown.

The Electrophysiology Divided Attention in older adults

Divided attention is a very dynamic process, with shifts in attention occurring rapidly, often in the order of milliseconds. Research using functional magnetic resonance imaging (fMRI) lacks the temporal resolution necessary to describe the dynamic changes that occur during divided attention, but is useful in indicating the brain regions involved. Overall, fMRI studies comparing performance on dual-tasks to single tasks find that dual-tasks elicit activation in frontal and parietal regions (Marois & Ivanoff, 2005). For example, Szameitat and colleagues (2002) had their participants perform an inter-modality dual-task (auditory and visual) and found that, when single-task activation was controlled for, dual-tasks elicited activation in areas such as the inferior frontal sulcus (IFS), middle frontal gyrus (MFG), and intraparietal sulcus (IPS). Other studies have shown similar findings, in addition to activation in more lateral prefrontal regions, which are implicated in executive functioning and task management (e.g., Schubert & Szameitat, 2003; Hartley et al., 2011; Alavash et al., 2016). Hartley and colleagues (2011) compared dual-task activation in younger adults to that of older adults during a PRP task involving two visual choice tasks (one with colours and one with letters). In terms of age-specific activations, the researchers observed that the older adults showed more activation in the right prefrontal cortex and in occipital regions (Hartley et al., 2011), though behaviourally performance in both age groups was equivalent.

Erickson and colleagues (2007) examined how divided attention cognitive training might impact the brains of older adults. They used two visual discrimination tasks (a colour and a letter discrimination task). Older adults had five 1-hour sessions of dual-task training over the span of three weeks with fMRI recordings taken during pre- and post-training test sessions. They observed increased activation in the left ventral prefrontal cortex (VLPFC) along with a decrease in dorsolateral PFC (DLPFC) activation in response to training. As both of these changes were correlated with behavioural improvements, the authors postulated that these results are suggestive of cognitive training-induced plasticity (Erickson et al., 2007).

While network activation during divided attention tasks is well-known, not as much information is available about the temporal dynamics of these activations, particularly in response to cognitive training. Thus, the use of imaging techniques with a high temporal resolution, such as EEG, is highly beneficial. Briefly, EEG is a non-invasive neuroimaging technique used for detecting voltage changes in brain neuronal populations through electrodes attached to the surface of the scalp. ERPs are post-synaptic potentials that occur in response to a specific event or stimulus. There are several ERP components of interest in the study of the mechanisms of attention.

The N1 component is an early sensory-evoked ERP. The visual N1 is thought to occur, in part, during visual discrimination processes, and thus tends to be enhanced for attended versus unattended stimuli (Vogel & Luck, 2000). As with many other processes, visual attention and discrimination are adversely impacted by aging. Wiegand and colleagues (2014) compared younger and older adults on a visual attention task, and found older adults to have a reduced N1, correlating with lower performance on the task. Furthermore, when the age groups were divided into high and low performers (based on a median split of a behavioural paradigm independent of EEG recordings), it was found that high performers had a more pronounced N1 than low-performers, suggesting that the deficits in low performers are visible on a neuronal level (Wiegand et al., 2014). The finding of reduced N1 amplitude in older adults has been replicated in multiple studies (Gazzaley et al., 2008; Zanto et al., 2010). In contrast, Alsius and colleagues found that the N1 of older adults appeared later under dual-task conditions but did not observe a change in amplitude relative to young adults (Alsius et al., 2014). Kida and colleagues (2011) had their young adult participants perform a visuo-motor tracking task along with a somatosensory oddball task and found that the amplitude of the somatosensory N1 was decreased with task repetition, suggesting an impact of practice on the N1 component. In summary, while the latency of the N1 component is reliably shown to be related to processing speed, the amplitude of the N1 remains ambiguous, particularly when looking at age-related changes.

Unlike the N1 component, considerably less research has been done on the P2 component, and of the research that has been conducted the results are often contradictory. The P2 is a positive deflection that tends to occur right after the N1, and is generally associated with some higher order cognitive functions, such as working memory (Lefebvre et al., 2005). The P2 is enhanced when stimuli contain target features (Amendo & Diaz, 1998; Pinal et al., 2015). With regards to aging, some researchers found the P2 to show a more frontal distribution and be enhanced in older adults compared to young ones during a working memory task (McEvoy et al., 2001). Pinal and colleagues (2015) used a working memory encoding task to compare brain physiology of older and younger adults. Their findings, contrary to those of McEvoy (2001), indicated that older adults had smaller P2 amplitudes that occurred later in the epoch compared to younger adults (Pinal et al., 2015). The researchers interpreted these findings as evidence of an age-related slowing of processing speed and neural resource availability in older adults.

Another event related waveform is referred to as the negative slow wave (NSW). The NSW is a sustained negativity that appears during working memory tasks but varies topographically based on task features. For example, a negative slow wave is generally seen in parietal brain regions during visuospatial tasks, while phonological tasks resulted in a more left anterior negativity (Ruchkin et al., 1990). Ruchkin and colleagues (1995) further elucidated the processes that this component reflected by showing a topographically distinct, more pronounced NSW in response to stimulus memorization but not stimulus preparation. Specifically, a strong right parietal and central NSW was observed when participants had to make a match/mismatch decision about stimuli locations, while merely having to prepare for a stimulus presentation did not elicit these NSWs, which were only observed (at a lower amplitude) in posterior regions (Ruchkin et al., 1995). Thus, a NSW would be expected to appear during relatively lengthy working memory and visuospatial tasks.

We previously indicated that divided attention involves a large network of brain regions; thus, it is beneficial to be able to examine the functional connectivity between those regions beyond independent site variations. EEG coherence analysis allows for the examination of the similarities between two signals as a function of both amplitude and frequency (Guevara & Corsi-Cabrera, 1996). The idea behind coherence is that an increase in the covariation between two electrodes after an experimental manipulation is indicative of an increase in the functional connectivity between the brain regions from which the signals originate. The impact of aging on EEG coherence is still poorly understood. Ho and colleagues (2011) compared younger and older adults' coherence while performing an auditory oddball task. Behaviourally, they observed that while accuracy on the task did not vary between the two groups, the older adults did take longer to respond to the stimuli. This was accompanied by a decrease in alpha (7-13 Hz) and beta (13-30 Hz) frequency bands' coherence between interhemispheric electrode pairs (F3-F4, C3-C4, and P3-P4), suggesting a decrease in cross-hemispheric connections with older age (Ho et al., 2011). Kawasaki, Kitajo, and Yamaguchi (2010) found increases in fronto-parietal theta but not alpha coherence during the manipulation period of a visual working memory task, indicating an increase in synchronization between those regions with increased cognitive load. Sauseng and colleagues (2006) showed that younger adults displayed higher fronto-occipital theta (4-7 Hz) and decreased anterior alpha coherence when required to switch rapidly between two tasks relative to performing a single task, suggesting a role for theta in these regions in cognitive control and establishing new task routines. Alpha coherence, on the other hand, has been associated with the suppression of irrelevant or distracting information during selective attention (Foxe & Snyder, 2011). Cocchi and associates (2011) examined brain coherence during the performance of a visuo-spatial working memory and visual discrimination dual-task. They found an increase in gamma and beta, but not alpha frequencies during dual-task performance (Cocchi et al., 2011). In summary, while the findings are mixed, variations in alpha and theta band coherence are generally observed in response to cognitive tasks, particularly under demanding conditions.

Few studies have examined EEG coherence in response to cognitive training. Langer and associates (2013) trained young adults on multiple cognitive tasks for one month (10 hours total) involving several aspects of working memory (e.g., retention, task switching, information integration). They found that, in addition to improvements in trained and some untrained tasks, trained participants displayed resting-state coherence changes in a fronto-parietal network, which correlated with behavioural improvements (Langer et al., 2013). Anguera and colleagues (2013) examined how cognitive training on a videogame dual-task influenced performance and EEG coherence in a group of older adults. Their dual-task involved steering a vehicle on a winding road while performing a visual detection task. Their findings indicated that one month (12 hours total) of training on performing multiple tasks concurrently had several benefits: A significant reduction in dual-task cost in trained individuals compared to single task training and no-contact controls, an effect that was still evident after 6 months; A reduction in dual-task cost in the older adults even when compared to untrained participants in their 20's; And far-transfer of benefits to tasks of sustained attention and working memory (Anguera et al., 2013). These benefits were associated with increased functional connectivity, as evidenced by increased theta frequency band coherence, between frontal and posterior brain regions. The authors conceptualize this increase in coherence as indicative of an enhancement in cognitive control abilities and a suppression of the default mode network (DMN) in these older adults in response to training. While these studies showed training-induced changes in coherence, no studies have looked at whether a variable attentional allocation training program would differentially impact coherence relative to normal (equal attention) dual-task training and single task practice.

Current Study

In the current investigation, we examined the impact of different dual-task training paradigms on older adults' divided attention abilities. Participants performed a dual-task consisting of a visual detection and a working memory alphanumeric equation task. They were randomly assigned to three training groups: The single task training group (STT, N=13) practiced each of the two tasks separately; the fixed attention training group (FAT, N=12) was trained to assign equal attention to both tasks concurrently; while the variable attention training group (VAT, N=14) was trained to assign variable amounts of attention while performing the tasks concurrently. We predicted that older adults trained to flexibly vary their attention will show the greatest improvement in response to training compared to the other two groups. Furthermore, in order to gain a better understanding of the dynamic cognitive processes taking place in response to training, we collected the participants' electrophysiological data via EEG before and after training. We predicted that training will result in more efficient processing of information that will be observable in the amplitude and latency of early sensory components such as the N1 and the P2. Moreover, variable attentional training will result in a change in functional connectivity between different brain regions, as measured by EEG coherence, indicating increased communication and task-coordination ability in response to training.

Materials & Methods

The experiment was conducted by Dr. Sylvie Belleville's lab at the Institut Universitaire de Gériatrie de Montréal (IUGM). All testing and data collection took place at the IUGM.

Ethics

This study was approved by the Institut universitaire de geriatrie de Montreal Human Ethics Committee and by The Regroupement Neuroimagerie/Quebec (RNQ) committee. Informed written consent was obtained from all subjects according to the Declaration of Helsinki.

Participants

Forty-one older adults between the ages of 60 and 84 were recruited from the community using adverts and posters in magazines and retirement centres. A telephone interview was conducted prior to the first session in order to ensure that the participants met the experiment's parameters. In order to be included in the study, participants had to be right-handed, French-speaking, with normal or corrected-to-normal vision and hearing. Participants were not included if they indicated the current presence or a history of any of the following: Alcoholism, substance abuse, serious health issues (e.g., epilepsy, metabolic dysfunction), dementia, stroke, medical conditions that could impact cognitive functioning or hand mobility, and severe psychiatric disorders (e.g., depression, bipolar disorder, and schizophrenia). In order to assess for the presence of mild cognitive impairment (MCI), participants were asked during the first session to complete the Montreal Cognitive Assessment scale (MoCA, Nasreddine et al., 2005), the geriatric depression scale (GDS, Yesavage, 1988), and the similarities and coding subtests of the WAIS-R (Wechsler, 1997).

Tasks

The study consisted of two tasks: An alphanumeric equation and a visual detection tasks. The two tasks were presented separately or simultaneously, depending on the testing condition, on a Compaq Pentium d530 computer screen, and responses were given on a keyboard.

Alphanumeric Equation Task. A working memory task, participants verified whether an equation (e.g., C-2= A) was correct or not. Equations always included two letters and one number related in a mathematical addition or subtraction operation. The range of letters used were A-M and the numbers were 1 or 2. Thus, an equation such as B + 2 = D might appear, which should prompt the participant to press the button corresponding to a “correct” equation. Equations containing the letter “I” were excluded to avoid confusion with the number “1”. 96 alphanumeric equations were designed, of which half were correct. The number of addition to subtraction, 1 to 2 digits, and correct to incorrect equations were equal within each block. The task was presented for 3500ms, followed by 1500ms fixation cross before the presentation of the next alphanumeric equation. Equations were presented in white over a black background in the centre of a ViewSonic GS773 17” screen using E-prime 1.1 software.

Visual Detection Task. Participants were presented with 1 x 8 cm rectangle below the center of the screen. The rectangle (or, bar) was either red or white. Participants responded with an appropriate key press only to the presence of a red rectangle on the computer monitor. Bars were presented in series of 5, with each bar being presented for a 500ms interval followed by a 250ms inter stimulus intervals (ISI) between bars. The number of red bars was counter-balanced throughout the trials. In a series of 5 bars, no less than 1 and no more than 3 red bars could potentially appear.

In the dual-task conditions, both tasks were presented on a screen simultaneously with the alphanumeric equation on the center of the screen and the detection bars slightly below center. During a single equation trial (3500ms), 5 potential detection targets were presented (500ms each with 250ms ISI), with between 1 and 3 red (target) bars that were randomized between trials. Response times and accuracy for each task were recorded. Response time was only included for correct trials.

Design

The study consisted of three stages: Pre-training test, training, and post-training test. See Appendix A for study design and stages.

Pre-training test. One to two weeks after the initial visit or phone interview, in which the participants were assessed for meeting the inclusion criteria of the study, they arrived for the pre-training test. On that day, all participants performed all of the following 4 conditions:

- Alphanumeric Equation focused attention, in which the equation task was performed alone.
- Visual Detection focused attention, in which the detection task was performed alone.
- Divided Attention 50/50 condition, in which participants performed both tasks at the same time (dual-task), with the instruction to give equal amount of attention to both tasks.
- Divided Attention 20/80 condition, in which participants performed both tasks at the same time (dual-task), with the instruction to give the majority of their attention (80%) to the detection task and a minimum amount (20%) to the alphanumeric equation task.

Participants underwent 4 blocks of the 4 conditions. In each block, there were 24 trials of each condition, for a total of 96 trials for each condition throughout testing. Trials were presented in an ABBA-like paradigm. EEG was recorded during the pre-training test.

Training. Training took place a week or two after the pre-training test. Training included Six 1-hour sessions over the course of two weeks. During training, participants performed 13 blocks of 20 trials each. The content of these trials differed based on group assignment. Participants were randomly assigned into one of three training groups:

- Single Task Training (STT) group: Control group. Participants trained on performing the alphanumeric equation task and the detection task separately.
- Fixed Divided Attention Training (FAT) group: participants performed the alphanumeric equation task and the detection task concurrently (dual-task training). They were instructed to allocate their attention equally between the two tasks (50-50).
- Variable Divided Attention Training (VAT) group: participants performed the alphanumeric equation task and detection task concurrently. They were instructed to variably allocate their attention between the two tasks (50%, 80-20%, 20-80%) in different blocks. Additionally, they completed two blocks of each of the single tasks before and after each training session in order to provide a baseline for providing performance feedback. At the end of each block, participants were shown performance histograms as a form of feedback to allow them to adjust their attentional allocation to match the block condition. These histograms contained two bars, one representing the participant's baseline accuracy on the single task, and the other showing the current

accuracy on the dual-task condition. A line delineating the desired performance threshold ran through the histogram.

Task instructions were both visually presented on the screen and read aloud to the participants. While the visual detection task was identical to the one performed during the pre- and post-training tests, the set of letters used during alphanumeric equation task training was N-Z, as opposed to the A-M range used in the pre- and post-training tests.

Post-training. One week after the end of training, participants were brought back to the laboratory for the post-training session. This session followed the same structure as the pre-training session, with all participants undergoing 4 blocks of the 4 conditions. EEG recordings were also taken during this session.

Dual-task cost

In addition to reporting the accuracy and reaction times for our participants' responses, we decided to determine if there were any speed-accuracy trade-offs during dual-task performance by calculating a dual-task cost as such:

$$Task\ Cost(Accuracy) = \frac{Accuracy(single\ task) - Accuracy\ (Dualtask)}{Accuracy\ (single\ task)}$$

$$Task\ Cost(ReactionTime) = \frac{RT(Dualtask) - RT(Single\ task)}{RT(single\ task)}$$

$$Total\ Task\ Cost = Task\ Cost(Accuracy) + Task\ Cost(ReactionTime)$$

$$DualTask\ Cost = Alphanumeric\ Total\ Cost + Detection\ Total\ Cost$$

Dual-cost was calculated separately for both the alphanumeric equation task and the detection task, then the two scores were added for each condition, giving us a global “dual-cost” value.

EEG Recording and processing

EEG was recorded using 64 Ag-AgCl electrodes organized in the standard 10-20 system (Jasper, 1958) using an electrode cap (Biosemi v. 6.04). Eye movement activity was recorded using electrodes placed near above, below, and to the sides of the right eye. The earlobes were used as a reference point for recording. During recording, the sampling rate was set to 512Hz with a low-pass filter of 100Hz.

Raw EEG data were processed using BrainVision Analyzer software (v. 2.1.1). The data was initially visually inspected and time periods with large distortions or no trials were marked as bad intervals (i.e., not analyzed). Data were corrected for DC drift artifacts and filtered using a 0.01Hz low cut-off and 45Hz high cut-off filters. Eye blinks and horizontal eye movements were corrected using an ocular correction algorithm as per Plank, 2013. Data were segmented into 5500ms epochs from -500 to 5000ms after the appearance of the alphanumeric equation. The only exception to this was in the Individual detection condition in which no equation was presented. In that condition, the epoch was time-locked to the appearance of the first detection bar in a series of 5. A semi-automatic artifact rejection algorithm was used to detect artifacts in our epochs, such as muscle activity and electrical interferences. No voltage steps over 50 μV/ms were allowed, nor a difference in voltage greater than 200 μV. All contaminated segments were excluded.

Event Related Potentials (ERPs)

Segments were baseline corrected to have the mean voltage between -500ms and 0ms be oμV. Averages for each condition were computed. Using a semi-automatic peak detection algorithm, we determined our two peaks of interest, the N1 and the P2. N1 was determined as the largest negative peak between 80-130ms, while P2 was determined as the largest positive peak between 130-220ms. The negative slow wave (NSW) was measured by computing the average amplitude (in μV) for nine latency ranges ,starting from 300ms and up to 750ms (300-350ms, 350-400ms, …., 700-750ms). All ERP analyses were conducted on nine midline electrodes (FPz, AFz, Fz, FCz, Cz, CPz, Pz, POz, and Oz).

Coherence

For coherence, we chose two time periods of interest based on a preliminary time-frequency analysis. These were 80-200 ms, which roughly corresponded to the appearance of our N1-P2 complex, and 800-950 ms, which roughly corresponded to the appearance of the second visual detection bar in a series. We segmented the data for each of these two time periods of interest. Fast fourier transformation (FFT) was applied to the data with a 10% hanning window and window variance correction. Magnitude squared coherence was then computed and a FisherZ transformation was done to allow normal distribution of values. Our two frequencies of interest were Theta (3.5-7.5 Hz) and Alpha (7.5-12.5 Hz). Electrode pairs of interest were chosen based on past research in the lab and in the literature. Four families of electrode pairs were separately analyzed:

- Cross-hemispheric electrode pairs: F3-F4, F7-F8, P7-P8, O1-O2
- Longitudinal midline electrode pairs: AFz-POz, AFz-Oz, Fz-POz, Fz-Oz

- Longitudinal left hemisphere electrode pairs: F3-P7, F3-O1, F7-P7, F7-O1
- Longitudinal right hemisphere electrode pairs: F4-P8, F4-O2, F8-P8, F8-O2

Statistical Analyses

For all behavioural results, we conducted a 2 x 3 mixed design ANOVA with Training (pre- vs. post-training) as our within-subjects variable and Group (STT vs. FAT vs. VAT) as our between subjects factor.

For the two ERP components (N1 and P2), we conducted a 2 x 9 x 3 mixed design ANOVA with Training (pre- vs. post-training) and Electrode (Fpz, AFz, Fz, FCz, Cz, CPz, Pz, POz, and Oz) as our within-subject factors, and training Group (STT vs. FAT vs. VAT) as the between subjects factor. We conducted these analyses separately for both the latency and the amplitude of our components.

For the negative slow wave (NSW), we conducted a 2 x 9 x 9 x 3 mixed design ANOVA with Training (pre- vs. post-training), Electrode (Fpz, AFz, Fz, FCz, Cz, CPz, Pz, POz, and Oz), and Time Period (nine 50 ms segments starting from 300 ms to 750 ms post-stimulus) as within-subject factors, and Training Group (STT vs. FAT vs. VAT) as the between subjects factor.

For coherence analyses, we conducted a 2 x 3 x 4 x 3 mixed design ANOVA with Training (pre- vs. post-training), Condition (Individual Equation, Individual Detection, and Dual-task 50/50 OR Dual-task 20/80), and Electrode Pair (four pairs based on the family being analyzed, see coherence section) as within-subject factors, and Training Group (STT vs. FAT vs. VAT) as the between subjects factor. Thus, separate ANOVAs were calculated for each combination of time period, frequency, electrode pair family, and dual-task condition.

In order to rule out the possibility of a speed-accuracy trade-off in our behavioural results, we calculated a “cost” value that represents the differences in reaction time and accuracy between single and dual task performance for our two dual-task conditions (for information on how this value was calculated, see Dual-task cost section above). We conducted a 2 x 3 x 3 mixed-model ANOVA with Training (pre- vs. post-training) and condition (Dual-task 50/50 vs. Dual-task 20/80) as our within-subjects variables, and Group (STT vs. FAT vs. VAT) as our between subjects factor.

Where appropriate, the Greenhouse-Geisser epsilon coefficient was used to adjust the P values for heterogeneity of variance and covariance (Jennings and Wood 1976). For our ERP and coherence results, we report the adjusted p-value along with the epsilon coefficient.

Results

Demographics:

To ensure that our groups were equivalent prior to training, we compared our 3 groups in terms of age, years of education, and sex. For age and education, this was done using two univariate ANOVAs with Group (STT vs. FAT vs. VAT) as our between subjects factor. For sex, a chi-square test was conducted. Participants in the three training groups did not differ significantly in age, sex, or education ($p>0.05$, see Table 1 for demographic information).

Two participants were excluded from our analyses due to abnormally low accuracy (<25%) and to EEG artifacts. A third participant was excluded from coherence analyses as an outlier due to consistently being > 2 standard deviations from the mean.

Alphanumeric Equation – Single Task

Accuracy. There was no effect of Group ($F(2, 36) = 0.044$, $p=0.96$, $\eta p^2 = 0.002$) nor a Training x Group interaction ($F(2, 36) = 1.89$, $p=0.17$, $\eta p^2 = 0.095$). When participants performed the alphanumeric equation task by itself, there was a main effect of Training on the participants' accuracy ($F(1, 36) = 50.25$, $p<0.001$, $\eta p^2 = 0.58$) as indicated by increases in accuracy from baseline (M=80.06%, SD=2.09) to after training (M=88.01%, SD=1.78; Figure 1).

Reaction Time. There was no effect of Group ($F(2, 36) = 0.25$, $p=0.78$, $\eta p^2 = 0.01$) nor a Training x Group interaction ($F(2, 36) = 0.197$, $p=0.82$, $\eta p^2 = 0.01$). Reaction time improved (decreased) significantly between pre- and post-training (Training effect: $F(1, 36) = 45.45$, $p<0.001$, $\eta p^2 = 0.56$; Figure 1).

Figure 2 illustrates the grand average waveform for the pre-versus post conditions, with a N1-P2 complex visible from approximately 100 to 200 ms post-stimulus, followed by a sustained negativity from 300 to 750 ms that gradually returned to baseline.

N1 Latency. There was no effect of Group (F (2, 36) = 1.38, p=0.26, ηp^2= 0.07, ε= 1.00) nor a Training x Group interaction (F (2, 36) = 1.06, p=0.36, ηp^2= 0.06, ε= 1.00). The participants' N1 wave appeared earlier post-training (Training effect: F(1, 36) = 6.597, p<0.05, ηp^2= 0.16, ε= 1.00). A main effect of Electrode (F(1, 36) = 4.24, p<0.01, ηp^2= 0.11, ε= 0.36) revealed that the N1 appeared earlier in occipital electrodes (Oz: 99.02 ms/2.58) compared to frontal ones (AFz: 112.23 ms/2.64). A Training x Electrode interaction (F(8, 288) = 4.03, p<0.01, ηp^2= 0.10, ε= 0.48) was observed that showed that the N1 component tended to appear earlier after training in frontal electrodes compared to pre-training (e.g., FPz, AFz, and Fz).

N1 Amplitude. There was no effect of Group (F (2, 36) = 0.09, p=0.91, ηp^2= 0.01, ε= 1.00) nor a Training x Group interaction (F (2, 36) = 0.85, p=0.85, ηp^2= 0.05, ε= 1.00). Participants' N1 component tended to have a less pronounced amplitude after training, though this effect did not reach significance (pre-training: -3.74uV/0.36; post-training: -3.23uV/0.26; Training effect: F(1, 36) = 3.75, p=0.061, ηp^2= 0.094, ε= 1.00). This amplitude varied based on the electrode's location (Electrode: F(8, 288) = 95.03, p<0.001, ηp^2= 0.73, ε=0.25), with a more negative distribution in frontal regions compared to posterior ones (Fz: -5.51 µV/0.49; POz: -1.49 µV/0.19).

P2 Latency. There was no effect of Training (F (1, 36) = 0.77, p=0.39, ηp^2= 0.02, ε= 1.00), Group (F (2, 36) = 2.77, p=0.08, ηp^2= 0.13, ε= 1.00) nor a Training x Group interaction (F (2, 36) = 0.51, p=0.60, ηp^2= 0.03, ε= 1.00). The P2 appeared earlier in occipital electrodes (Oz:

147.72 ms/3.496) compared to frontal ones (AFz: 161.80 ms/2.896; Electrode effect: F(8, 304)=7.83, p<0.001, ηp^2= 0.17, ε= 0.47).

P2 Amplitude. There was no effect of Training (F (1, 36) = 0.78, p=0.38, ηp^2= 0.02, ε= 1.00), Group (F (2, 36) = 2.35, p=0.11, ηp^2= 0.12, ε= 1.00) nor a Training x Group interaction (F (2, 36) = 0.61, p=0.55, ηp^2= 0.03, ε= 1.00). The P2 was generally more pronounced in frontal electrodes compared to occipital ones (Oz: -2.71 μV/0.36; AFz: 2.06 μV/0.63; Electrode effect: F(8, 304)=23.36, p<0.001, ηp^2= 0.38, ε= 0.20).

NSW Amplitude. There was no effect of Training (F (1, 36) = 0.09, p=0.76, ηp^2= 0.003, ε= 1.00), Group (F (2, 36) = 0.12, p=0.89, ηp^2= 0.01, ε= 1.00), nor a Training x Group interaction (F (2, 36) = 0.20, p=0.82, ηp^2= 0.01, ε= 1.00) in the amplitude of the participants' NSW. The NSW was largest in central electrodes (FCz: -4.49 μV/0.67) compared to occipital ones (Oz: -0.35 μV/0.37; Electrode effect: (F(8, 304)=14.30, p<0.001, ηp^2= 0.27, ε= 0.265). We observed two interactions that approached significance: a Time Period x Electrode interaction (F(64, 2432)=3.67, p<0.05, ηp^2= 0.09, ε= 0.052) and a Training x Time Period x Electrode interaction F(64, 2432)=2.99, p<0.005, ηp^2= 0.07, ε= 0.093). Analysis of the simple effects making up these interactions revealed a general trend for posterior electrodes (particularly POz) to show a more positive distribution post-training in the latter half of our designated time periods (450 ms and later, see Figure 2).

In summary, when participants performed the alphanumeric equation task alone, training increased task performance (both accuracy and RT). Our ERP results showed an earlier yet less pronounced N1 amplitude in frontal electrodes. No changes were observed in the P2 and NSW components.

Visual Detection – Single Task

Accuracy. Participants were asked to perform the visual detection task alone by pressing a button when a red bar appears on the screen. Participants had high accuracy (Figure 3) even before training (M=95.87%, SD=0.82), likely due to the simplicity of the task, with small but reliable improvements after training (M=96.65%, SD=0.69; Training effect: F (1, 36) = 4.21, $p<0.05$, ηp^2= 0.11). No effects of Group (F (2, 36) = 2.37, p=0.11, ηp^2= 0.12) or a Training x Group effect (F (2, 36) = 0.17, p=0.85, ηp^2= 0.01) were found.

Reaction Time. Differences in reaction time were also subtle between baseline (M=348.88 ms, SD=5.77) and post-training (M=342.34 ms, SD=5.38; Figure 3). Yet this difference still approached significance (Training effect: F (1, 36) = 3.86, p=0.057, ηp^2= 0.097). No effects of Group (F (2, 36) = 0.48, p=0.62, ηp^2= 0.03) or a Training x Group effect (F (2, 36) = 0.72, p=0.49, ηp^2= 0.04) were found.

Figure 4 shows the grand average waveform for the pre-versus post conditions, with a N1-P2 complex visible from approximately 100 to 200 ms post-stimulus, followed by a sustained negativity from 300 to 750 ms that gradually returned to baseline.

N1 Latency. There was no effect of Training (F (1, 36) = 1.79, p=0.19, ηp^2= 0.05, ε= 1.00), Group (F (2, 36) = 1.08, p=0.35, ηp^2= 0.06, ε= 1.00), nor a Training x Group interaction (F (2, 36) = 0.04, p=0.97, ηp^2= 0.002, ε= 1.00).

N1 Amplitude. There was no effect of Training (F (1, 36) = 0.45, p=0.51, ηp^2= 0.01, ε= 1.00), Group (F (2, 36) = 0.45, p=0.65, ηp^2= 0.02, ε= 1.00), nor a Training x Group interaction (F (2, 36) = 0.36, p=0.70, ηp^2= 0.02, ε= 1.00). The amplitude of the N1 was more pronounced (more negative) in frontal compared to central and posterior electrodes (AFz: -4.24 µV/0.49; Cz:

-2.99 µV/0.44; POz: -0.59 µV/0.13; Electrode effect: $F(8, 288)=52.15$, $p<0.001$, $\eta p^2= 0.59$, $\varepsilon= 0.197$).

<u>P2 Latency.</u> There was no effect of Training ($F (1, 36) = 0.11$, $p=0.74$, $\eta p^2= 0.003$, $\varepsilon= 1.00$), Group ($F (2, 36) = 0.95$, $p=0.396$, $\eta p^2= 0.05$, $\varepsilon= 1.00$), nor a Training x Group interaction ($F (2, 36) = 1.19$, $p=0.32$, $\eta p^2= 0.06$, $\varepsilon= 1.00$).

<u>P2 Amplitude.</u> There was no effect of Training ($F (1, 36) = 0.04$, $p=0.84$, $\eta p^2= 0.001$, $\varepsilon= 1.00$) nor Group ($F (2, 36) = 0.39$, $p=0.68$, $\eta p^2= 0.02$, $\varepsilon= 1.00$). The amplitude of the P2 was more pronounced in electrodes FPz and AFz (FPz: 1.76 µV/0.48; AFz: 1.84 µV/0.49) than in electrode Oz (-0.47 µV/0.34; Electrode effect: $F(8, 288)= 6.42$, $p<0.005$, $\eta p^2= 0.15$, $\varepsilon=0.22$). We observed a Training x Group interaction ($F(2, 36)=3.74$, $p<0.05$, $\eta p^2= 0.17$, $\varepsilon=1.00$), showing that the amplitude of the P2 component in the STT component was enhanced after training (STT pre: 0.92 µV/0.54; post: 2.04 µV/0.56; $p=0.025$), an effect that was not evident for the other two groups (FAT pre: 1.16 µV/0.56; FAT post: 0.56 µV/0.61; VAT pre: 1.51 µV/0.52; VAT post: 1.17 µV/0.56). A Training x Group x Electrode 3-way interaction ($F(16, 288)=2.93$, $p<0.05$, $\eta p^2= 0.14$, $\varepsilon=0.36$) was observed, indicating that frontal and central electrodes were more affected by this shift than were occipital ones.

<u>NSW Amplitude.</u> Due to the nature and simplicity of performing the Detection task alone, we observed no clear negative slow wave (see Figure 4).

To summarize, training improved participants' performance when doing the visual detection task alone. Furthermore, performing the task alone did not significantly alter EEG readings between the groups, with the exception of an enhanced P2 amplitude in response to STT training, with no significant changes in FAT and VAT groups.

Dual-task (50% Equation, 50% Visual Detection)

Equation Accuracy. On the equation task, accuracy varied as a function of Training (F(1, 36)=37.76, p<0.001, ηp^2= 0.51) with accuracy increasing from pre-training to post-training, as seen in Figure 5. We observed no effect of Group (F (2, 36) = 2.12, p=0.80, ηp^2= 0.11), nor a Training x Group interaction (F (2, 36) = 2.12, p=0.14, ηp^2= 0.11).

Equation Reaction Time. Reaction time improved as a function of Training (F(1, 36)=22.09, p<0.001, ηp^2= 0.38) with post-training performance being faster than pre-training on average (Figure 5). The equation task did not vary with Group (F (2, 36) = 0.59, p=0.56, ηp^2= 0.03), nor did it show a Training x Group interaction (F (2, 36) = 0.23, p=0.798, ηp^2= 0.01).

Detection Accuracy. Visual detection accuracy improved with training (F(1, 36)=50.579, p<0.001, ηp^2= 0.58) and we observed a Training x Group interaction (F(2, 36)=4.89, p<0.05, ηp^2= 0.21) showing that all three groups significantly improved on the visual detection task after training (all p<0.05). Furthermore, the VAT group had higher accuracy than the FAT group after training (FAT post: 51.996%/5.11; VAT post: 69.98%/4.73; Figure 6). Accuracy did not vary with Group (F (2, 36) = 1.82, p=0.18, ηp^2= 0.09).

Detection Reaction Time. There was no effect of Training (F (1, 36) = 1.93, p=0.17, ηp^2= 0.05) or Group (F (2, 36) = 0.72, p=0.49, ηp^2= 0.04). However, there was a Training x Group effect that approached significance (F(2, 36)=3.23, p=0.051, ηp^2= 0.15). This interaction revealed that the VAT group significantly improved after training, while the improvements in the other two groups were not significant (Figure 6).

Figure 7 illustrates the grand average waveform for the pre-versus post conditions, with a N1-P2 complex visible from approximately 100 to 200 ms post-stimulus, followed by a sustained negativity from 300 to 750 ms.

N1 Latency. There was no effect of Training (F (1, 36) = 2.77, p=0.11, ηp^2= 0.07, ε= 1.00), Group (F (2, 36) = 0.61, p=0.55, ηp^2= 0.03, ε= 1.00), nor a Training x Group interaction (F (2, 36) = 1.91, p=0.16, ηp^2= 0.096, ε= 1.00). The N1 appeared earlier at frontal electrodes (AFz: 112.33 ms/2.26; Fz: 111.67 ms/2.48) compared to occipital ones (Oz: 100.07 ms/3.39; F (8, 288) = 4.62, p<0.01, ηp^2= 0.11, ε= 0.35). There was Training x Electrode interaction (F(8, 288)=3.62, p<0.01, ηp^2= 0.09, ε= 0.501) which showed that the N1 appeared earlier in certain electrodes (FPz pre: 114.596 ms/2.48; FPz post: 108.795 ms/2.91; Cz pre: 115.297 ms/3.66 ; Cz post: 107.69 ms/2.72).

N1 Amplitude. The N1 component was less pronounced (less negative) post-training (pre-training: -4.18 µV/0.42; post-training: -2.97 µV/0.28; Training effect: F(1, 36)=11.25, p<0.01, ηp^2= 0.24, ε=1.00). The N1 component was significantly more pronounced in frontal electrodes (AFz: -5.61 µV/0.52) compared to central (Cz: -4.49 µV/0.47) and posterior electrode (POz: -1.49 µV/0.16; Electrode effect: F(8, 288)=67.99, p<0.001, ηp^2= 0.65, ε=0.20). There was a Training x Electrode interaction (F(8, 288)=4.84, p<0.01, ηp^2= 0.12, ε=0.31), showing that the N1 was less pronounced after training in frontal and central electrodes (FPz, AFz, Fz, FCz, Cz, and CPz). There was no effect of Group (F (2, 36) = 0.25, p=0.78, ηp^2= 0.01, ε= 1.00) nor a Training x Group interaction (F (2, 36) = 0.68, p=0.52, ηp^2= 0.04, ε= 1.00).

P2 Latency. There was no effect of Training (F (1, 36) = 1.81, p=0.19, ηp^2= 0.05, ε= 1.00), nor a Training x Group interaction (F (2, 36) = 1.60, p=0.22, ηp^2= 0.08, ε= 1.00). The latency of the P2 at the Oz electrode was earlier than all other electrodes (Cz: 166.22 ms/2.54; Oz: 148.79 ms/3.995; Electrode effect: F(8, 288)=7.77, $p<0.001$, ηp^2= 0.18, ε=0.41). A Group effect was observed (F(2, 36)=3.57, $p<0.05$, ηp^2= 0.165, ε=1.00) showing that the FAT and VAT groups significantly differed from each other with the VAT P2 appearing later (Mean difference= 12.77 ms/4.799). A Training x Electrode x Group interaction was found (F(16, 288)=1.99, $p<0.05$, ηp^2= 0.099, ε=0.55), with the FAT group showing an earlier P2 post-training (CPz post: 161.09 ms/4.17) in central electrodes compared to pre-training (CPz pre: 170.21 ms/4.16). It should be noted that group comparisons for this component are difficult to interpret due to a pre-training difference between our groups, as the STT group had an earlier P2 than the FAT and VAT groups before training.

P2 Amplitude. We observed a main effect of Training (F(1, 36)=5.85, $p<0.05$, ηp^2=0.14, ε=1.00), Electrode position (F(8, 288)=16.95, $p<0.001$, ηp^2= 0.32, ε=0.19), and a Training x Electrode interaction (F(8, 288)=3.00, $p<0.05$, ηp^2= 0.08, ε=0.399). These effects showed that, in frontal and central electrodes, the P2 was more pronounced post-training (Cz post: 2.84 µV/0.58) compared to pre-training (Cz pre: 1.71 µV/0.69). We observed a Training x Group interaction which showed a trend towards significance (F(2, 36)=2.896, $p=0.068$, ηp^2= 0.139, ε=1.00). The simple effects of this interaction revealed that the FAT group was the only one to significantly change after training (FAT pre: 0.75 µV/0.84; FAT post:1.298 µV/0.80), $p<0.01$). Comparison of the different groups was difficult due to a pre-training difference between the FAT and VAT groups, indicating that the FAT P2 was significantly more negative before training. There was no effect of Group (F (2, 36) = 1.81, $p=0.18$, ηp^2= 0.09, ε= 1.00).

NSW Amplitude: There was no effect of Training ($F (1, 36) = 1.56$, $p=0.22$, $\eta p^2= 0.04$, $\varepsilon= 1.00$), Group ($F (2, 36) = 1.15$, $p=0.33$, $\eta p^2= 0.06$, $\varepsilon= 1.00$), nor a Training x Group interaction ($F (2, 36) = 1.42$, $p=0.26$, $\eta p^2= 0.07$, $\varepsilon= 1.00$). We observed a main effect of Time Period ($F(8, 288)=8.22$, $p<0.001$, $\eta p^2= 0.19$, $\varepsilon=0.25$), and Electrode ($F(8, 288)=7.87$, $p<0.001$, $\eta p^2= 0.18$, $\varepsilon=0.26$) as well as a Time Period x Electrode interaction ($F(64, 2304)=9.11$, $p<0.001$, $\eta p^2= 0.20$, $\varepsilon=0.06$). Analysis of these effects showed that the NSW tended to be at its most negative at the beginning of the time period (300-450 ms) and mainly in frontal electrodes (FPz and AFz). We observed a Training x Group x Time Period 3-way interaction that approached significance ($F(16, 288)=2.16$, $p=0.063$, $\eta p^2= 0.11$, $\varepsilon=0.32$). Analysis of the simple effects of this interaction indicated that the FAT group was the only group to significantly change from pre- to post-training (FAT pre: -3.698 μV/0.95; FAT post: -2.28 μV/0.72), showing a less pronounced NSW post training, particularly in the latter time periods (600-750 ms, Figure 7).

In summary, when asked to divide attention equally between the two tasks, all training groups improved their performance at both tasks, yet the VAT group showed a significantly larger improvement in accuracy and reaction time of the visual detection task. All groups showed a less pronounced N1 at frontal sites post-training. The P2, on the other hand, appeared earlier and was stronger post-training in the FAT group.

Dual-task (20% equation, 80% visual detection)

Equation Accuracy. During the equation task, seen in Figure 8, participants' accuracy varied with Training ($F(1, 36)=28.64$, $p<0.001$, $\eta p^2= 0.44$) with an increase in accuracy post-training . Accuracy also showed a Training x Group interaction ($F (2, 36) = 3.45$, $p<0.05$, $\eta p^2= 0.16$), which showed that the STT and FAT groups significantly improved after training, while the VAT group's improvement did not reach significance ($p>0.05$). Despite the VAT group not showing any significant improvement, all three groups were comparable after training (both $p>0.05$). There was no effect of Group ($F(2, 36) = 0.146$, $p=0.87$, $\eta p^2 = 0.01$) in this condition.

Equation Reaction Time. Reaction time on the equation task only varied with Training ($F(1, 36) = 11.37$, $p=0.01$, $\eta p^2 = 0.24$) due to a decrease in RT post-training. There was no effect of Group ($F(2, 36) = 0.48$, $p=0.63$, $\eta p^2 = 0.03$, $\varepsilon = 1.00$), nor a Training x Group interaction ($F(2, 36) = 0.49$, $p=0.62$, $\eta p^2 = 0.03$, $\varepsilon = 1.00$).

Detection Accuracy. Performance accuracy on the visual detection task varied based on Training ($F(1, 36) = 24.31$, $p<0.001$, $\eta p^2 = 0.40$), showing that accuracy improved after training. We observed an effect of Group ($F(2, 36) = 4.54$, $p<0.05$, $\eta p^2 = 0.20$), showing that the VAT group had higher accuracy than the FAT group on average. This was further elucidated by a Training x Group interaction ($F(2, 36) = 7.34$, $p<0.01$, $\eta p^2 = 0.29$; Figure 9) which showed that the VAT group had significantly higher accuracy than the FAT group, but only post-training. The interaction also indicated that the STT and VAT groups were the only ones to significantly increase from pre- to post-training.

Detection Reaction Time. Reaction time for the detection task improved with training (Training effect: $F(1, 36)=18.47$, $p<0.001$, $\eta p^2 = 0.34$). We observed a Training x Group interaction ($F(2, 36)=6.43$, $p<0.05$, $\eta p^2 = 0.26$), which showed that the STT and VAT groups significantly reduced their reaction time after training (Figure 9). There was no effect of Group ($F(2, 36) = 0.895$, $p=0.42$, $\eta p^2 = 0.05$, $\varepsilon = 1.00$) in this condition.

Figure 10 illustrates the grand average waveform for the pre-versus post conditions, with a N1-P2 complex visible from approximately 100 to 200 ms post-stimulus, followed by a sustained negativity from 300 to 750 ms.

N1 Latency. The N1 component appeared earlier in the Oz electrode compared to all other electrodes (Cz: 111.24 ms/2.62; Oz: 92.18 ms/2.81; Electrode effect: $F(8, 288)=10.67$, $p<0.001$, $\eta p^2= 0.23$, $\varepsilon=0.34$). The latency of the N1 also showed an effect of Training, though it only approached significance ($F(1, 36)=3.72$, $p=0.062$, $\eta p^2= 0.09$, $\varepsilon=1.00$), indicating that the N1 appeared earlier post-training (pre: 109.63 ms/2.09; post: 106.61 ms/2.10). There was no effect of Group ($F (2, 36) = 0.35$, $p=0.71$, $\eta p^2= 0.02$, $\varepsilon= 1.00$), nor a Training x Group interaction ($F (2, 36) = 0.59$, $p=0.56$, $\eta p^2= 0.03$, $\varepsilon= 1.00$).

N1 Amplitude. The N1 was less pronounced post-training ($F(1, 36)=4.32$, $p<0.05$, $\eta p^2= 0.11$, $\varepsilon=1.00$). We observed an effect on Electrodes ($F(8, 288)=89.40$, $p<0.001$, $\eta p^2= 0.71$, $\varepsilon=0.23$), with a more negative distribution at frontal electrodes that increased in positivity moving towards more posterior electrodes (AFz: -6.33 µV/0.53; Cz: -4.57 µV/0.42; POz: -1.52 µV/0.17). There was no effect of Group ($F (2, 36) = 0.42$, $p=0.66$, $\eta p^2= 0.02$, $\varepsilon= 1.00$), nor a Training x Group interaction ($F (2, 36) = 1.38$, $p=0.26$, $\eta p^2= 0.07$, $\varepsilon= 1.00$).

P2 Latency. There was no effect of Training ($F (1, 36) = 0.35$, $p=0.56$, $\eta p^2= 0.01$, $\varepsilon= 1.00$), Group ($F (2, 36) = 1.36$, $p=0.27$, $\eta p^2= 0.07$, $\varepsilon= 1.00$), nor a Training x Group interaction ($F (2, 36) = 2.36$, $p=0.11$, $\eta p^2= 0.12$, $\varepsilon= 1.00$). The latency of the P2 wave varied with electrode positions ($F(8, 288)=7.67$, $p<0.001$, $\eta p^2= 0.18$, $\varepsilon=0.47$) due to the P2 appearing earlier in electrode Oz compared to other electrodes (Cz: 169.59 ms/3.05; Oz: 149.76 ms/4.32).

P2 Amplitude. The P2 was more pronounced after training (pre: 0.83uV/0.45; post: 1.54uV/0.45; Training effect: F (1, 36) = 4.29, $p<0.05$, $\eta p^2 = 0.11$, $\varepsilon=1.00$). We observed a Training x Group interaction (F (2, 36) = 3.56, $p<0.05$, $\eta p^2 = 0.17$, $\varepsilon=1.00$), showing that the FAT group was the only one to significantly change in P2 amplitude (more pronounced) after training (FAT pre: -0.78 µV/0.82; FAT post: 1.15 µV/0.81; $p<0.01$). The interaction also revealed a pre-training difference between the FAT and VAT groups, with the FAT having a significantly less pronounced P2 prior to training compared to VAT (FAT pre: -0.78 µV/0.82; VAT pre: 2.22 µV/0.76; $p<0.05$). There was no effect of Group (F (2, 36) = 1.70, p=0.197, $\eta p^2 = 0.09$, $\varepsilon= 1.00$).

NSW Amplitude. There was no effect of Training (F (1, 36) = 1.04, p=0.32, $\eta p^2 = 0.03$, $\varepsilon= 1.00$), Group (F (2, 36) = 2.55, p=0.09, $\eta p^2 = 0.12$, $\varepsilon= 1.00$), nor a Training x Group interaction (F (2, 36) = 0.36, p=0.70, $\eta p^2 = 0.02$, $\varepsilon= 1.00$). The NSW was most pronounced at central electrodes which were significantly more negative than occipital ones (Cz: -3.99 µV/0.58; POz: -0.36 µV/0.25; Electrode effect: F (8, 288) = 7.76, $p<0.005$, $\eta p^2 = 0.18$, $\varepsilon=0.25$). We also observed an effect of Time Period (F (8, 288) = 6.77, $p<0.005$, $\eta p^2 = 0.16$, $\varepsilon=0.25$) showing that the NSW was more pronounced in earlier time periods (300-600 ms) compared to later ones (600-700 ms). Finally, an Electrode x Time Period interaction was observed (F (64, 2304) = 7.25, $p<0.001$, $\eta p^2 = 0.17$, $\varepsilon=0.05$), showing that the NSW was more pronounced in frontal and central electrodes, and that this effect was evident in earlier time period (300-600 ms) compared to later ones.

In summary, when asked to devote the majority of their attention towards the simpler visual detection task, all groups had improved accuracy and RT at both tasks post-training, with the greatest improvements being observed in the FAT group for the alphanumeric equation task, and in the VAT group for the detection task. With regards to ERPs, we observed an earlier yet less pronounced frontal N1 after training, particularly in the FAT group. The P2 was more pronounced in the FAT group as well.

Coherence:

Due to the sheer volume of coherence results obtained here we will only report relevant effects of Training, Group, Condition or their interactions. All other results are summarized in Table 2. Cross-hemisphere electrode pairs did not display any relevant interactions in any of our time periods and frequencies and are therefore not included in the results.

Region 1 (80-200 ms) – Alpha.

Midline Electrode Pairs.

Dual-task 50/50. We observed no effect of Training (F (1, 35) = 2.07, p=0.16, ηp^2= 0.06, ε= 1.00), Group (F (2, 35) = 0.34, p=0.72, ηp^2= 0.02, ε= 1.00), Condition (F (2, 70) = 0.66, p=0.50, ηp^2= 0.02, ε= 0.895), nor a Training x Group interaction (F (2, 35) = 0.61, p=0.55, ηp^2= 0.03, ε= 1.00). We observed a Condition x Group interaction (F (4, 70) = 3.51, $p<0.05$, ηp^2= 0.17, ε= 0.895) showing that the VAT group's alpha coherence in the Individual Detection condition was lower than the Individual Equation and Dual-task 50/50 conditions (p's < 0.05, Figure 11).

Dual-task 20/80. We observed no effect of Training (F (1, 35) = 0.77, p=0.39, ηp^2= 0.02, ε= 1.00), Group (F (2, 35) = 1.44, p=0.25, ηp^2= 0.08, ε= 1.00), nor a Training x Group interaction (F (2, 35) = 1.29, p=0.29, ηp^2= 0.07, ε= 1.00). We observed an effect of Condition (F (2, 70) = 5.195, $p<0.01$, ηp^2= 0.13, ε= 0.98) showing that alpha coherence was higher in the

Divide 20/80 condition than the two single task conditions (Figure 11).

Longitudinal Left Hemisphere Electrode Pairs.

Dual-task 50/50. We observed no effect of Training (F (1, 35) = 1.36, p=0.25, ηp^2= 0.04, ε= 1.00), Condition (F (3, 70) = 0.31, p=0.64, ηp^2= 0.01, ε= 0.65), Group (F (2, 35) = 0.54, p=0.59, ηp^2= 0.03, ε= 1.00), nor a Training x Group interaction (F (2, 35) = 0.26, p=0.78, ηp^2= 0.01, ε= 1.00) in this condition.

Dual-task 20/80. We observed no effect of Training (F (1, 35) = 1.74, p=0.196, ηp^2= 0.05, ε= 1.00), Condition (F (3, 70) = 1.14, p=0.31, ηp^2= 0.03, ε= 0.73), Group (F (2, 35) = 1.49, p=0.24, ηp^2= 0.08, ε= 1.00), nor a Training x Group interaction (F (2, 35) = 0.86, p=0.43, ηp^2= 0.05, ε= 1.00) in this condition.

Longitudinal Right Hemisphere Electrode Pairs.

Dual-task 50/50. We observed no effect of Training (F (1, 35) = 0.52, p=0.48, ηp^2= 0.01, ε= 1.00), Group (F (2, 35) = 0.97, p=0.39, ηp^2= 0.05, ε= 1.00), nor a Training x Group interaction (F (2, 35) = 1.96, p=0.16, ηp^2= 0.10, ε= 1.00). Alpha coherence was higher in the Individual Detection condition relative to the Dual-task 50/50 condition (Condition effect: F (2, 70) = 4.46, p=0.02, ηp^2= 0.11, ε= 0.88). We observed a Training x Condition interaction which approached statistical significance (F (2, 70) = 3.64, p=0.053, ηp^2= 0.09, ε= 0.65) showing that the Dual-task 50/50 condition had decreased alpha coherence after training, an effect not seen in the single task conditions (Figure 12). The interaction also revealed that the Individual Detection condition had higher alpha coherence after training compared to the other two conditions, while all three groups were equivalent prior to training.

Dual-task 20/80. We observed no effect of Training (F (1, 35) = 1.54, p=0.22, ηp^2= 0.04, ε= 1.00), Group (F (2, 35) = 1.82, p=0.18, ηp^2= 0.09, ε= 1.00), nor a Condition effect (F (2, 70) = 2.81, p=0.08, ηp^2= 0.07, ε= 0.87). We observed a Training x Group interaction (F (2, 35) = 4.10, $p<0.05$, ηp^2= 0.19, ε= 1.00), shown in Figure 13, which indicated a pre-training difference in our groups wherein the FAT group had higher alpha coherence than the other two groups, an effect which disappeared after training. The interaction also indicated that the FAT group was the only one to change from pre- to post-training, showing a decrease in alpha coherence. We observed a Training x Condition interaction (F (2, 70) = 3.80, $p<0.05$, ηp^2= 0.098, ε= 0.93) showing that, before training, alpha coherence was higher in the Dual-task 20/80 compared to the Individual Equation condition. After training, the Individual detection condition had higher coherence than the Individual Equation condition. The interaction also revealed that the Dual-task 20/80 condition was the only condition to significantly decrease after training (pre-training: 0.092/0.01; post-training: 0.063/0.008; Figure 12).

Region 1 (80-200 ms) – Theta.

Midline Electrode Pairs.

Dual-task 50/50. We observed no effect of Training (F (1, 35) = 0.195, p=0.66, ηp^2= 0.01, ε= 1.00), Condition (F (2, 70) = 0.09, p=0.90, ηp^2= 0.002, ε= 0.90), Group (F (2, 35) = 0.499, p=0.61, ηp^2= 0.03, ε= 1.00). A Training x Group interaction approached significance (F (2, 35) = 2.62, p=0.087, ηp^2= 0.13, ε= 1.00) and showed that the VAT group was the only one to show increased theta coherence in response to training (VAT pre: 0.12/0.03; VAT post: 0.22/0.04; Figure 14). The interaction also revealed a pre-training difference in our groups suggesting that the FAT group had significantly more theta coherence than the VAT group prior to training (FAT pre: 0.23/0.03).

Dual-task 20/80. We observed no effect of Training (F (1, 35) = 0.29, p=0.59, ηp^2= 0.01, ε= 1.00), Condition (F (2, 70) = 0.15, p=0.86, ηp^2= 0.004, ε= 0.98), Group (F (2, 35) = 0.08, p=0.93, ηp^2= 0.004, ε= 1.00). A Training x Group interaction approached significance (F (2, 35) = 2.52, p=0.095, ηp^2= 0.13, ε= 1.00) and showed that the VAT group was the only one to show increased theta coherence in response to training (VAT pre: 0.13/0.03; VAT post: 0.23/0.04; Figure 14). The interaction also revealed a pre-training difference in our groups suggesting that the FAT group had significantly more theta coherence than the VAT group prior to training (FAT pre: 0.22/0.03). We observed a 4-way Training x Group x Condition x Electrode Pair interaction (F (12, 210) = 2.15, $p<0.05$, ηp^2= 0.11, ε= 0.71) showing that electrode-pairs in the VAT group uniquely showed increased theta coherence in response to training. Specifically, theta coherence in the AFz-Oz electrode pair increased during the Individual Detection condition (Figure 15), while coherence in the AFz-POz electrode pair increased during the Dual-task 20/80 condition (Figure 16).

Longitudinal Left Hemisphere Electrode Pairs.

Dual-task 50/50. We observed no effect of Training (F (1, 35) = 0.001, p=0.991, ηp^2= 0.001, ε= 1.00), Condition (F (2, 70) = 0.98, p=0.38, ηp^2= 0.03, ε= 0.98), Group (F (2, 35) = 0.59, p=0.56, ηp^2= 0.03, ε= 1.00) nor a Training x Group interaction (F (2, 35) = 0.88, p=0.42, ηp^2= 0.05, ε= 1.00). A 3-way Training x Condition x Group approached significance (F (4, 70) = 2.19, p=0.084, ηp^2= 0.11, ε= 0.94). Examining the simple effects of this interaction showed that the VAT group's theta coherence increased in the Individual Detection condition after training.

Dual-task 20/80. We observed no effect of Training (F (1, 35) = 0.18, p=0.68, ηp^2= 0.005, ε= 1.00), Condition (F (2, 70) = 1.52, p=0.23, ηp^2= 0.04, ε= 0.84), Group (F (2, 35) = 0.47, p=0.63, ηp^2= 0.03, ε= 1.00). We observed a Training x Group interaction (F (2, 35) = 3.78, p<0.05, ηp^2= 0.18, ε= 1.00), showing a pre-training difference between our groups in which the FAT group had higher theta coherence than the VAT group prior to training. A 3-way Training x Condition x Group interaction was observed (F (4, 70) = 4.49, p<0.01, ηp^2= 0.20, ε= 0.98) showing that theta coherence increased in response to VAT group training during both the Individual Detection and Dual-task 20/80 conditions (Figure 17). The FAT group theta coherence showed a decrease in response to training during the Dual-task 20/80 condition.

Longitudinal Right Hemisphere Electrode Pairs.

Dual-task 50/50. We observed no effect of Training (F (1, 35) = 0.02, p=0.90, ηp^2= 0.001, ε= 1.00), Condition (F (2, 70) = 1.05, p=0.35, ηp^2= 0.03, ε= 0.91), Group (F (2, 35) = 0.71, p=0.497, ηp^2= 0.04, ε= 1.00) nor a Training x Group interaction (F (2, 35) = 0.52, p=0.599, ηp^2= 0.001, ε= 1.00).

Dual-task 20/80. We observed no effect of Training (F (1, 35) = 0.36, p=0.55, ηp^2= 0.01, ε= 1.00), Condition (F (2, 70) = 0.02, p=0.95, ηp^2= 0.001, ε= 0.77), Group (F (2, 35) = 0.58, p=0.56, ηp^2= 0.03, ε= 1.00) nor a Training x Group interaction (F (2, 35) = 2.52, p=0.095, ηp^2= 0.13, ε= 1.00).

Region 2 (800-950 ms) – Alpha.

Midline Electrode Pairs.

Dual-task 50/50. We observed no effects of Training (F (1, 35) = 0.03, p=0.86, ηp^2= 0.001, ε= 1.00), Condition (F (2, 70) = 0.91, p=0.41, ηp^2= 0.03, ε= 0.97), Group (F (2, 35) = 1.13, p=0.33, ηp^2= 0.06, ε= 1.00), nor a Training x Group interaction (F (2, 35) = 0.71, p=0.50, ηp^2= 0.04, ε= 1.00).

Dual-task 20/80. We observed no effects of Training (F (1, 35) = 0.07, p=0.79, ηp^2= 0.002, ε= 1.00), Condition (F (2, 70) = 0.59, p=0.56, ηp^2= 0.02, ε= 0.85), Group (F (2, 35) = 0.79, p=0.46, ηp^2= 0.04, ε= 1.00), nor a Training x Group interaction (F (2, 35) = 0.05, p=0.96, ηp^2= 0.003, ε= 1.00). We observed a 3-way Training x Condition x Electrode Pair interaction (F (6, 210) = 3.01, $p<0.05$, ηp^2= 0.08, ε= 0.81) which indicated that the AFz-POz electrode pair had lower alpha coherence than the Fz-Oz pair before but not after training. No other significant simple effects were found.

Longitudinal Left Hemisphere Electrode Pairs.

Dual-task 50/50. We observed no effects of Training (F (1, 35) = 0.02, p=0.898, ηp^2= 0.001, ε= 1.00), Condition (F (2, 70) = 0.495, p=0.58, ηp^2= 0.01, ε= 0.83), Group (F (2, 35) = 2.35, p=0.11, ηp^2= 0.12, ε= 1.00), nor a Training x Group interaction (F (2, 35) = 0.14, p=0.87, ηp^2= 0.01, ε= 1.00).

Dual-task 20/80. We observed no effects of Training (F (1, 35) = 0.23, p=0.63, ηp^2= 0.01, ε= 1.00), Condition (F (2, 70) = 0.195, p=0.80, ηp^2= 0.01, ε= 0.90), Group (F (2, 35) = 1.897, p=0.17, ηp^2= 0.098, ε= 1.00), nor a Training x Group interaction (F (2, 35) = 0.57,

$p=0.57$, $\eta p^2 = 0.03$, $\varepsilon = 1.00$).

Longitudinal Right Hemisphere Electrode Pairs.

Dual-task 50/50. Training resulted in a decrease in participants' alpha coherence (pre-training: 0.088/0.01; post-training: 0.064/0.01; $F(1, 35) = 6.41$, $p<0.05$, $\eta p^2 = 0.16$, $\varepsilon = 1.00$; Figure 18). We observed no effect of Group ($F(2, 35) = 0.41$, $p=0.67$, $\eta p^2 = 0.02$, $\varepsilon = 1.00$), nor a Training x Group interaction ($F(2, 35) = 0.19$, $p=0.83$, $\eta p^2 = 0.01$, $\varepsilon = 1.00$) in this condition.

Dual-task 20/80. Training resulted in a decrease in participants' alpha coherence (pre-training: 0.090/0.01; post-training: 0.067/0.01; $F(1, 35) = 5.53$, $p<0.05$, $\eta p^2 = 0.14$, $\varepsilon = 1.00$; Figure 18). A Training x Group x Condition 3-way interaction approached significance ($F(4, 70) = 2.58$, $p=0.053$, $\eta p^2 = 0.13$, $\varepsilon = 0.88$) which indicated a training-induced decrease in STT alpha coherence during the Individual Equation condition ($p=0.02$), a decrease in FAT alpha coherence during the Dual-task 20/80 condition ($p=0.01$), and a decrease in VAT alpha coherence during the Individual detection condition, though that last one only approached significance ($p=0.07$; Figure 19). We observed no effect of Group ($F(2, 35) = 1.27$, $p=0.29$, $\eta p^2 = 0.07$, $\varepsilon = 1.00$), nor a Training x Group interaction ($F(2, 35) = 0.20$, $p=0.82$, $\eta p^2 = 0.01$, $\varepsilon = 1.00$).

Region 2 (800-950 ms) – Theta.

Midline Electrode Pairs.

Dual-task 50/50. We observed no effects of Training ($F(1, 35) = 0.15$, $p=0.71$, $\eta p^2 = 0.004$, $\varepsilon = 1.00$), Condition ($F(2, 70) = 0.31$, $p=0.68$, $\eta p^2 = 0.01$, $\varepsilon = 0.77$), Group ($F(2, 35) = 0.61$, $p=0.55$, $\eta p^2 = 0.03$, $\varepsilon = 1.00$), nor a Training x Group interaction ($F(2, 35) = 1.698$, $p=0.198$, $\eta p^2 = 0.09$, $\varepsilon = 1.00$). We observed a Group x Condition interaction ($F(4, 70) = 2.86$, $p<0.05$, $\eta p^2 = 0.14$, $\varepsilon = 0.77$) showing that the VAT group's theta coherence in the Individual

Equation condition was significantly higher than the other two conditions. We observed a significant 3-way Training x Group x Electrode Pair interaction (F (6, 105) = 4.66, $p<0.005$, $\eta p^2 = 0.21$, $\varepsilon = 0.62$) which showed that the STT group theta coherence at the Fz-Oz electrode pair decreased after training, while the FAT group's theta coherence at the AFz-Oz pair increased after training.

Dual-task 20/80. We observed no effects of Training (F (1, 35) = 0.24, p=0.63, $\eta p^2 =$ 0.01, $\varepsilon = 1.00$), Condition (F (2, 70) = 0.63, p=0.53, $\eta p^2 = 0.02$, $\varepsilon = 0.98$), Group (F (2, 35) = 0.03, p=0.97, $\eta p^2 = 0.002$, $\varepsilon = 1.00$), nor a Training x Group interaction (F (2, 35) = 2.52, p=0.095, $\eta p^2 =$ 0.13, $\varepsilon = 1.00$). We observed a Group x Condition interaction (F (4, 70) = 4.23, $p<0.01$, $\eta p^2 =$ 0.195, $\varepsilon = 0.98$) which showed that theta coherence was overall lower in the VAT group relative to the FAT group during performance of the Individual Detection condition.

Longitudinal Left Hemisphere Electrode Pairs.

Dual-task 50/50. We observed no effects of Training (F (1, 35) = 0.05, p=0.83, $\eta p^2 =$ 0.001, $\varepsilon = 1.00$), Condition (F (2, 70) = 0.69, p=0.47, $\eta p^2 = 0.02$, $\varepsilon = 0.76$), Group (F (2, 35) = 0.42, p=0.66, $\eta p^2 = 0.02$, $\varepsilon = 1.00$), nor a Training x Group interaction (F (2, 35) = 1.35, p=0.27, $\eta p^2 = 0.07$, $\varepsilon = 1.00$).

Dual-task 20/80. We observed no effects of Training (F (1, 35) = 1.19, p=0.28, $\eta p^2 =$ 0.03, $\varepsilon = 1.00$), Condition (F (2, 70) = 0.88, p=0.39, $\eta p^2 = 0.03$, $\varepsilon = 0.73$), Group (F (2, 35) = 0.13, p=0.88, $\eta p^2 = 0.01$, $\varepsilon = 1.00$), nor a Training x Group interaction (F (2, 35) = 1.15, p=0.33, $\eta p^2 =$ 0.06, $\varepsilon = 1.00$).

Longitudinal Right Hemisphere Electrode Pairs.

Dual-task 50/50. We observed no effects of Training (F (1, 35) = 0.29, p=0.59, ηp^2= 0.01, ε= 1.00), Condition (F (2, 70) = 1.61, p=0.21, ηp^2= 0.04, ε= 0.99), Group (F (2, 35) = 0.97, p=0.39, ηp^2= 0.05, ε= 1.00), nor a Training x Group interaction (F (2, 35) = 1.16, p=0.33, ηp^2= 0.06, ε= 1.00). We observed Group x Condition interaction (F (4, 70) = 2.68, $p<0.05$, ηp^2= 0.13, ε= 0.99) which showed that theta coherence in the Individual Detection condition was significantly higher in the FAT group relative to the other two training groups.

Dual-task 20/80. We observed no effects of Training (F (1, 35) = 0.60, p=0.44, ηp^2= 0.02, ε= 1.00), Condition (F (2, 70) = 1.35, p=0.27, ηp^2= 0.04, ε= 0.84), Group (F (2, 35) = 0.37, p=0.69, ηp^2= 0.02, ε= 1.00), nor a Training x Group interaction (F (2, 35) = 1.26, p=0.44, ηp^2= 0.02, ε= 1.00).

Dual-task cost analyses:

The results showed a main effect of Training (F(1, 36)=26.34, $p<0.001$, ηp^2= 0.42) and a Training x Group interaction (F(2, 36)=4.44, $p<0.05$, ηp^2= 0.198) showing that training significantly reduced dual-task cost in the VAT group, but not the other two groups (Figure 20). Furthermore, Dual cost was significantly lower in the VAT group than the FAT group, but only after training. The ANOVA also revealed a main effect of condition (F(1, 36)=12.27, p=0.001, ηp^2= 0.25) showing that dual cost was generally lower in the Divide 20/80 condition compared to the Dual-task 50/50 condition. Although the Training x Group x Condition 3-way interaction did not reach significance (F(2, 36)=0.11, $p>0.05$, ηp^2=0.006), we examined the simple effects making up this interaction as we had an apriori hypothesis regarding this relationship. Indeed, our findings revealed that while all three groups had a significantly reduced dual cost for the Dual-task 20/80 condition after training compared to pre-training, only the VAT group showed this effect for the Dual-task 50/50 condition as well ($p<0.001$). We observed no effect of Group ($F(2, 36) = 1.65$, $p=0.21$, $\eta p^2= 0.08$, $\varepsilon= 1.00$). Overall, our cost analyses suggest that while all groups lowered their dual-task cost after training, the VAT group showed the most significant reduction compared to the other two groups, regardless of the testing condition.

Discussion

In the present study, we investigated the behavioural and electrophysiological impact of different cognitive training paradigms on divided attention task performance in older adults. Our participants were trained to either perform the two tasks making up the dual-task separately (STT), to perform the dual-task while giving equal attention to both tasks (FAT), or to perform the dual-task while flexibly varying their attentional allocation (VAT). Our findings indicate global behavioural benefits for training on task performance for all three of our groups. These global improvements were reflected in our ERP findings by a reduced N1 wave and an enhanced P2 wave, both markers of more efficient processing. Participants who were trained to flexibly vary their attention (VAT) improved their dual-task performance beyond the global increase seen in the other two groups. This was associated with an increase in functional connectivity in the theta band between fronto-parietal and fronto-occipital regions in this group. We will start by examining our behavioural findings and how they were affected by our different training programs, then we will address our electrophysiological findings and relate them to the behavioural findings. The functional connectivity variations seen in the alpha and theta frequency bands will be addressed in the context of our behavioural and ERP findings. Finally, we will examine some methodological and theoretical considerations in the current investigation and avenues for future research.

Training effects on task performance.

As reported earlier, participants had to complete two tasks, an alphanumeric equation and a visual detection task, under varying conditions. In general, training improved single task performance (accuracy and reaction times) for all our participants, regardless of the training approach provided. In addition to the two single task conditions, we had two dual-task conditions: one in which participants were instructed to give equal attention to the two tasks (Dual-task 50/50), and one in which they were instructed to allocate the majority of their attention towards the visual detection task (Dual-task 20/80). Despite these instructions, we observed that most participants treated the alphanumeric equation task as the primary and the visual detection as secondary, as evidenced by the higher baseline accuracy on the alphanumeric equation task relative to the detection task in both dual-task conditions. In the two dual-task conditions, we saw group-specific changes during the two dual-task conditions. This was mainly exemplified by an improvement in the VAT group's accuracy and reaction time while performing the visual detection task that was not seen in the other groups. This is congruent with previous findings on the beneficial impact of attentional flexibility training (Kramer et al., 1995, 1999; Gopher et al., 2000). Three unique aspects of this variable attention training likely played a role in the observed benefits. The first is the metacognitive aspects of the training itself (see Hertzog et al., 2008), as the VAT group acquired flexible attentional allocation skills that were not provided to the other two groups and which allowed them to adapt to task demands and rapidly switch between tasks without sacrificing performance. The second aspect of this training is the feedback provided to this group during training, which displayed performance histograms and allowed participants to gain a better estimate of the amount of attentional focus they allocated to the two tasks during a given training session. Finally, the variable training, by its nature, involved different training conditions, leading to a more heterogeneous training environment, which is said to modestly improve dual-task performance (Lussier et al., 2015). All of these aspects are consistent with Schmidt and Bjork's (1992) principles for efficient training and learning, which suggest that training is most beneficial when participants are allowed to approach a task in different and sometimes challenging ways, such as the different prioritization training conditions that the VAT group underwent. Furthermore, Schmidt & Bjork (1992) suggested that performance feedback makes the learnt information more useful and more immediate, thus resulting in better learning overall, consistent with our findings in the current investigation.

Interestingly, the behavioural benefits we observed were most pronounced during performance of the visual detection task in dual-task conditions, while performance on the alphanumeric equation task globally improved for all our training groups. The detection task was undeniably the simpler of the two tasks, yet it also required constant monitoring by our participants as the switch from one bar to the next took less than a second to occur (by comparison, the equation remained on the screen for three and a half seconds). Thus, since the VAT-specific benefits were only observed in dual-task conditions, this suggests that the variable attentional training resulted in better task coordination and attentional control skills that led to better performance on the detection task. As our dual-task cost calculations showed a reduction in dual-task cost exclusively in our VAT group, this suggests that the aforementioned improvements were not the result of a speed-accuracy trade-off, nor was it due to these participants sacrificing performance on the alphanumeric task as performance increased or did not change with VAT training.

While the current study did not include a younger adults (YA) group, comparison with studies of YAs might shed some light on the unique mechanisms and adaptations seen in OAs. For example, Kramer and colleagues (1995, 1999) observed benefits for a variable attentional training paradigm compared to a fixed one in both young and older adults; however, these findings tended to be more pronounced in older adults, indicating that variable training specifically improved an area in which OAs are more deficient than YAs (Kramer et al., 1995). One suggestion comes from Gazzaley and colleagues (2005), who showed that some of the deficits seen in OAs are related to an inability to suppress task-irrelevant information. Along the same lines, Mozolic and associates (2011) showed that attentional training programs focused on improving older adults' ability to suppress irrelevant information had tangible performance improvements. In our design, the white bars during the detection task, to which no response is required, could be conceptualized as distractors for the alphanumeric equation and the target detection bars. While purely speculative, we suggest that variable attentional training improved older adults' ability to supress said distractors leading to improved performance, particularly in accuracy and reaction times to target bars (red bars) which were improved in this group. Another area of weakness in OAs which might be improved by training is task-switching. OAs show higher reaction time switching costs relative to YAs when required to rapidly switch between two tasks (Meiran et al., 2001). Indeed, Basak and colleagues (2008) showed that a variety of OA's executive functions, including task switching, were improved using a real-time strategy video-game training paradigm, which required flexible attentional allocation to various goals in order to achieve success. Thus, it is conceivable that variable allocation training allowed our participants to improve their ability to rapidly switch between the two experimental tasks, leading to better overall dual-task performance.

Training effects on ERP components

We examined the ERPs associated with our dual-task paradigm under different levels of attentional allocation. Our study focused mainly on the N1 and P2 components, and the NSW. N1 and P2 are early sensory-evoked components that have been found to vary with factors such as the amount of attention devoted to a stimulus and specific target features (Vogel & Luck, 2000; Amendo & Diaz, 1998). Thus, we predicted that our training protocols would induce electrophysiological changes in our participants reflecting more efficient processing of information. Our findings indicated that the N1 component tended to appear earlier and was less pronounced after training across all three of our groups, particularly in frontal regions. Most of the literature suggests an enhancement of the N1 component following cognitive training (Mishra et al., 2015; Berry et al., 2009), or, alternatively, that an enhancement of N1 is more distinct in younger adults and is associated with better behavioural performance on cognitive tasks (Weigland et al., 2014). For example, Mishra and colleagues (2015) found that, following perceptual training in older adults, an enhancement of the visual N1 component was observed in occipital regions, which was associated with better performance on a paired sweeps task. To address the discrepancy between these findings and our study, some points are worth discussing. A distinction should be made between the posterior and the anterior N1 components, as they have been shown to represent different processing components (Di Russo et al., 2003; Weigland et al., 2014). The posterior N1 has been mainly associated with neural resource availability and is seen as an index of processing speed (Vogel & Luck, 2000). In contrast, the anterior N1 is related to the processing and encoding of task-relevant features (Golomb et al., 2010). In the current study, we observed an N1 component with a distinctly anterior topography (see Appendix B for a typical N1 topography in our study). This anterior N1 was reduced after training, yet showed a trend toward appearing earlier. These findings were not observed in the Individual Detection condition, suggesting that they are related to the processing of the alphanumeric equation. Interestingly, Kida and associates (2011) have shown a decrease in N1 amplitude with repetition under both single- and dual-task conditions. Thus, the observed decrease could be a generalized practice effect, namely, automation of the alphanumeric equation task.

Our behavioural findings support this hypothesis as they show that, before training, participants had higher accuracy on the equation task regardless of the attentional allocation instructions given to them. Assuming that the visual detection task would be the easiest of the two for most people, this phenomenon suggests a prioritization of the equation task, leading to higher accuracy. Thus, after training, participants on average were able to decrease attentional allocation to the alphanumeric equation and redistribute it to the dual-task while improving performance.

The P2 component is said to index working memory function (Lefebvre et al., 2005). As memory and attention are highly interrelated, we opted to examine the effects of attentional training on this component. We observed an enhanced P2 component after training, particularly in our FAT group. These results are difficult to interpret as very few cognitive training studies have looked at P2 variation, even less so in attentional training. Thus, while the current study did not involve younger adults, contrasting our findings with those of studies looking at age-related differences in P2 might shed some light on the potential effects of training. Pinal and associates (2015) observed a suppressed P2 in older adults compared to young adults during the encoding stage of a delayed match to sample (DMS) task. The researchers interpreted this suppression as a deficit in processing resources allocated to the task (Pinal et al., 2015). Similarly, our findings here might reflect increased neuronal recruitment of attentional resources with training. This interpretation is presented with caution as findings with the P2 have been mixed, with some researchers finding an enhancement of older adults' P2 relative to young adults (McEvoy et al., 2001).

Put together, the two ERP components examined here showed a suppression of the N1 and an enhancement of the P2 after training, which we believe reflects an automation of the alphanumeric equation task along with improved neuronal recruitment of processing resources. Our N1 and P2 findings suggest generalized training effects that were observed in all our groups, including the participants that were trained to perform the individual tasks separately. Thus, the nature of these findings is likely closer to "practice effects" than training ones. In other words, the findings in the N1 and P2 ERPs are likely the result of continued exposure and practice of the two experimental tasks (be it separately or together). Using dipole source localization techniques, Di Russo and colleagues (2003) showed that the posterior N1 originates in the extrastriatal occipital cortex, while the anterior N1 is in the superior parietal cortex close to the intraparietal sulcus (IPS), an area that has been associated with dual-task performance (Herath et al., 2001). On the other hand, P2 is said to originate from parieto-occipital regions, which are highly involved in working memory processing (Freunberger et al., 2007; Finnigan et al., 2011).

In addition to EEG, fMRI data was also collected during this study and reported by Belleville & colleagues (2014). The fMRI scans revealed no unique training-related activation (Post-training>Pre-training) in the STT group while performing the dual-task. Conversely, the FAT group showed increased activation in the right superior and middle frontal gyrus in the Dual-task 50/50 condition only, while the VAT group showed the same activation in the Dual-task 50/50 and Dual-task 20/80 conditions (Belleville et al., 2014). While bearing in mind the spatial limitations of EEG, activation in the frontal gyrus, which is associated with cognitive control, roughly corresponds to EEG electrodes Cz and Fz on the international 10-20 coordinates system (Giacometti et al., 2014). In accordance with this, most of the ERP changes we observed in response to training tended to occur in these electrodes. However, our ERP findings were not exclusive to the VAT group and were generalized to all training groups. This discrepancy might be reconciled by considering the differences between the two imaging techniques. Our EEG findings were focused on a very small time period in order to capture minute temporal variations in activation that are not detected by fMRI, however it is also possible that fMRI captures prolonged activations that we were unable to observe. Other fMRI findings, such as those from Erickson and colleagues (2007), found a benefit for dual-task training which correlated with brain changes in the dorsolateral and ventrolateral prefrontal cortex without any frontal gyrus activation.

The negative slow wave (NSW) has generally been associated with sustained attention and working memory function (Looren de Jong et al., 1988; Ruchkin et al., 1995; Drew et al., 2006). Our findings showed a difference in the NSW between our dual-task condition and the alphanumeric equation single task conditions in that the NSW was more negative in the latter. No differences in the NSW were observed in response to training, however. Our findings seem to suggest that the effects of training tend to occur earlier in the epoch (such as those seen in the N1 and P2) and might also be more related to functional connectivity between different regions (as seen in our coherence findings). Nonetheless, it is also possible that the epoch we chose (300-750 ms post-stimulus) was not sufficient to demonstrate the NSW changes. The appearance of the NSW varies greatly by the experimental task (Mecklinger & Pfeifer, 1996; Ruchkin et al., 1990; Berti et al., 2000), and can be observed as late as 1000ms post-stimulus (Ruchkin et al., 1995).

The N2 component was not included in this study as it was not consistently identified in our sample and was often merged with the NSW without forming a distinct peak. Nonetheless, the N2 is also modulated by attention and is said to be involved in cognitive control processes (for review, see Folstein & Van Petten, 2008). The N2 is also elicited by trials that require no response (such as no-go trials in a go/no-go task) and so as our ERPs were not differentiated based on the identity of the visual detection bar (target or non-target) that might have contributed to the lack of dissociable N2 components.

Training effects on functional connectivity as measured by EEG Coherence

Coherence has been conceptualized as a high time resolution measure of dynamic connectivity between different brain regions (Guevara & Corsi-Cabrera, 1996; Ruchkin, 2005). The brain is a complex array of interconnected networks, and thus the assessment of synchronous oscillatory activity can be more informative than single-region activations as it elucidates the communication between distant but functionally related neuronal networks (Sauseng & Klimesch, 2008). In the current investigation, we examined coherence in two time periods, roughly corresponding to the appearance of our N1 and P2 components (80-200 ms), and the appearance of the second visual detection bar in our epoch (800-950 ms). The first time period was chosen as it represents early dual-task processing. The second time period represents the processing of a detection bar after the initial equation processing is done. The findings are discussed below.

Alpha coherence. We found that alpha band coherence decreased after training in right fronto-parietal and fronto-occipital electrode pairs. This occurred in both of our time periods of interest, but in the first time period it was only the dual-task conditions that decreased in response to training. Alpha band coherence is associated with sensory and perceptual task variations (Schurmann et al., 1997; Hummel & Gerloff, 2005) and is generally thought to reflect cortical inhibition (Cooper et al., 2003; Sauseng et al., 2005). Previous studies have observed a decrease in alpha coherence in response to increasing task demands on a visuospatial working memory task, reflecting increased attention to the task (Sauseng et al., 2005). Similar findings were observed when participants had to rapidly switch between two tasks (Sauseng et al.,2006). Furthermore, researchers have suggested that alpha reduction is suggestive of an attentional suppression mechanism (Foxe & Snyder, 2011). Thus, our findings of decreased alpha coherence likely reflect our participants' ability supress attention to irrelevant stimuli (such as the white detection bars) and thus improve their efficiency at the dual-tasks.

Theta Coherence. We observed an increase in theta band coherence in response to training that was mostly limited to our VAT group in the first time period. This increase was seen in the first time period in fronto-parietal (AFz-POz) and fronto-occipital (AFz-Oz) electrode pairs, particularly in conditions where the visual detection task is emphasized (Individual Detection and Dual-task 20/80 condition). In the second time period, the pattern of results was more mixed.

fMRI and PET studies have long demonstrated an increase in activity in prefrontal and posterior regions related to working memory and cognitive control functions (e.g., Marklund et al., 2007; Krause et al., 2006). Moreover, neuroimaging shows that this frontal activity is decreased in older adults, including in the anterior cingulate cortex (ACC) which is one of the generators of theta activity in the brain (Raghavachari et al., 2006). Increases in theta band activity have been found to predict better cognitive performance on working memory and sustained attention tasks (Reichert et al., 2016; Kardos et al., 2014; McEvoy et al., 2001). Indeed, theta modulation is said to be deficient in older adults, as evidenced by studies showing an enhancement of theta power in younger adults du ring successful trials of working memory tasks compared to errors, an effect not seen in older adults (Kardos et al., 2014). Similar patterns were found in younger and older adults when comparing theta activity to relevant versus irrelevant stimuli (Gazzaley et al., 2008). Cognitive training in younger and older adults resulted in an increase in theta band power. Specifically, working memory training induced an increase in theta power in occipito-parietal and frontal regions in younger adults (Nyberg et al., 2003), while older adults only showed the increase in occipito-parietal regions (Olesen et al., 2004).

Studies of theta band coherence have found that increased coherence in fronto-posterior regions was associated with working memory function (Sarnthein et al., 1998; Kopp et al., 2004; but see Onton et al., 2005 for negative findings) and task-switching (Sauseng et al., 2006). This has led some researchers to suggest that fronto-posterior theta coherence is reflective of information integration and cognitive control during working memory tasks (Sauseng et al., 2007). Our findings here of a post-training increase in theta coherence in our VAT group support the notion that training in that group led to the acquisition of improved attentional control strategies, as evidenced by the improved behavioural performance and reduced dual-task costs.

To the best of our knowledge, the only study to examine theta coherence in a dual-attention cognitive training paradigm comes from Anguera and colleagues (2013). In their study, younger and older adults were trained on a driving video-game dual-task and theta coherence and power were examined. Similar to our findings, older adults that were trained to “multitask” (that is, trained on doing both tasks together) showed an improved performance along with increased theta power and coherence in fronto-parietal regions. The current investigation differs from the Anguera study in that we included a variable attentional training (VAT) group. The "multitask" training group in the Anguera study most closely resembles the FAT group in our design, which our findings indicated showed an increase in theta coherence but only in our later time period (800-950 ms). On the other hand, our VAT group showed increases in theta coherence most prominently in our first time period (80-200 ms), suggesting functional communication occurred earlier during dual-task processing in this group. Previous studies have suggested that older adults use more effortful and less efficient strategies during complex tasks (McEvoy et al., 2001), and that the learning of more efficient strategies can alter brain plasticity (Kramer et al., 1995; Belleville et al., 2014; Erickson et al., 2007). Thus, our findings suggest that synchronisation of theta oscillation between frontal and more parietal/occipital regions is a form of regulatory top-down cognitive control mechanism by frontal regions to association areas (Miller & Cohen, 2001).

A complementary interpretation for the relationship between increased theta coupling and performance has to do with activity of the default mode network (DMN). The DMN is generally activated under "neutral" conditions and deactivated during cognitively demanding tasks (Raichle et al., 2001). The DMN involves a large number of interconnected regions including the medial prefrontal cortex (mPFC), posterior cingulate cortex (PCC), and the hippocampus (Raichle et al., 2001; Fox et al., 2005). Previous research has shown that fronto-medial theta oscillatory power was negatively correlated with activity in the DMN during working memory tasks (Scheeringa et al., 2008), and that this relationship was stronger for correct than incorrect trials (White et al., 2013). In older adults, the degree of deactivation of the DMN is less than that of younger adults (Lustig et al., 2003; Grady et al., 2006), suggesting that older adults' lower performance on cognitive tasks might be in part due to inefficient suppression of default networks. While speculative, our findings and those of Anguera (2013) of increased theta coherence after training might reflect increased deactivation of the DMN in older adults, contributing to increased attention to the tasks by our participants, leading to better performance.

Limitations of the current investigation

While the three training groups were randomly selected and showed no significant differences in age, sex, or level of education, we observed several instances of pre-training differences in our analyses. These differences were almost always caused by variations in the FAT group, and were still there even after a couple of outliers were excluded from analyses. Inter-individual variability is likely the cause for these observed deviations. While these differences make group comparisons difficult, it does not impact the robustness of our reported within-groups training effects.

The generalizability and transferability of cognitive training effects has been the subject of debate in the literature. Ball and colleagues (2002) attempted to determine the impact of cognitive training on activities of daily living of older adults. Looking at 2832 older adults from the ACTIVE (Advanced Cognitive Training for Independent and Vital Elderly) study group, the researchers found that while cognitive training resulted in improvements in the function that the older adults were trained in (for example, individuals that underwent memory training had better performance on memory tasks), it had no effect on their instrumental activities of daily living (iADL) and driving habits (a good measured of divided attention) when assessed at 12 and 24 months after training (Ball et al., 2002). Conversely, a recent 10-year follow-up of the same sample (reduced to N=1211) found that older adults' perceived difficulty on IADLs was decreased in the cognitive training groups compared to controls (Rebok et al., 2014). Therefore, the researchers postulate that cognitive changes might precede changes in daily function by several years, or, alternatively, that changes in neuronal function might take place over a number of years (Rebok et al., 2014). The current investigation did not examine the transfer effects of our training protocols to generalized functions. It should be noted, however, that Bier and colleagues (2014) tested the participants of this study one week after training on an n-back task along with the primary outcome measure. Their results show significant improvements in 1-back reaction time for the FAT and VAT groups after training, though all three groups improved equally on the 2-back condition, possibly due to a ceiling effect (Bier et al., 2014). It remains to be seen whether these transfer benefits are related to the coherence changes we observed in our study.

Two limitations of the current investigation are the duration and the follow-up time after training. Some cognitive training paradigms, such as the aforementioned ACTIVE study (Ball et al., 2002; Rebok et al., 2014), have found benefits of training that persevered up to 10 years afterwards. On the other hand, Mahncke and colleagues (2006) observed immediate effects of their memory enhancement cognitive training program which were not there 3 months later. In our current study, participants were only tested once one week after training, and thus it is not possible to infer longitudinal effects of our training. The duration of training was also a possible limitation. Our training paradigm was relatively short (6 hours of training over 2 weeks); however, the idea with the VAT group was to teach attentional control strategies that the participants could apply in different contexts. Thus, a longer training period would not necessarily be more beneficial. Nonetheless, it would be of considerable interest to examine the effects of a longer, more intensive training period on our paradigm.

One important methodological consideration when examining coherence data is the possibility of volume conduction. Volume conduction is a propagation of a signal through the brain and thus it being detected by multiple electrodes. This might result in an “artificial” synchronization effect, showing coherence between two electrodes that do not share any functional connectivity (Khadem & Hossein-Zadeh, 2014). Correlations between our behavioural findings and EEG coherence displayed an incoherent pattern which may suggest the possibility of volume conduction. In contrast, conduction is unlikely to occur between electrodes that are further than 2 cm away from one another, while we observed coherence effects extending from frontal (AFz) to occipital (Oz) electrodes. Furthermore, our theta coherence findings resemble topographical distributions found in other studies in regions associated with attentional control. Finally, several of our analyses (e.g., cross-hemispheric electrode pairs’ coherence) showed no significant coherence effects in any of the pairs examined. This suggests that volume conduction was likely not significant enough to interfere with our findings.

While our ERP findings showed global changes in response to cognitive training, as evidenced by the reduced N1 and enhanced P2 components, it should be noted that our analyses were limited to midline electrodes, as visual inspection of our grand averages showed effects that were centered around the midline. Yet as we observed in our coherence findings, some lateral electrodes do show changes in response to training and thus examining these electrodes might have revealed more nuanced group-specific electrophysiological changes. Finally, the sample size in our study was relatively small.

Future directions

Several studies that examined working memory and attentional function in older adults have found consistent electrophysiological differences between high and low performers (eg., Wiegand et al., 2014; Daffner et al., 2012; Fukuda & Vogel, 2009). Fukuda and Vogel (2009, experiment 1) divided healthy older adults into low and high capacity groups based on a median split of an independent visual working memory task. They then showed that low capacity older adults had a stronger N1 response to distractor items than high capacity older adults, suggesting a deficit in the ability to inhibit processing of irrelevant information for the former group (Fukuda & Vogel, 2009). As previously noted, the FAT group showed several pre-training differences despite being matched on demographic factors. This points to the importance of considering individual differences beyond health and neuropsychological factors, particularly in groups such as older adults, where age-related differences are not as well-understood.

Physical activity in older adults has emerged as an alternative to “pure” cognitive training with promising results showing an improvement in cognitive abilities, such as executive functions, in response to physical exercise paradigms (Renaud et al., 2010; Berryman et al., 2014). Combining a variable cognitive training paradigm with physical exercise might have synergistic effects on participants’ learning abilities. As cognitive training is relatively cost-efficient, it is feasible to combine it with a number of interventions. For example, some researchers have suggested combining cognitive training with medication for both healthy and demented older adults (Yesavage et al., 2007).

Conclusion

This study offers behavioural and physiological evidence of specialized effects in response to a cognitive training procedure. Healthy older adults that underwent a cognitive training procedure improved their performance on a visual detection and alphanumeric equation dual-task. All training groups showed electrophysiological changes in response to training that corresponded to more efficient processing of the tasks. A training group that underwent flexible attentional allocation strategy (VAT) training showed improvements beyond those seen in the other two groups, suggesting a benefit for variable learning and feedback. This group also displayed increased functional connectivity in fronto-parietal and fronto-occipital regions in the theta band, suggesting improved cognitive control and task-switching ability. Our findings demonstrate the unique benefits of teaching older adults cognitive control strategies and stress the importance of a targeted training approach that is focused on teaching metacognitive skills as opposed to simple repetition.

References

Alavash, M., Thiel, C. M., & Gießing, C. (2016). Dynamic coupling of complex brain networks and dual-task behavior. *NeuroImage*, *129*, 233–246. http://doi.org/10.1016/j.neuroimage.2016.01.028

Alsius, A., Möttönen, R., Sams, M. E., Soto-Faraco, S., & Tiippana, K. (2014). Effect of attentional load on audiovisual speech perception: Evidence from ERPs. *Frontiers in Psychology*, *5*(JUL), 1–9. http://doi.org/10.3389/fpsyg.2014.00727

Amenedo, E., & Díaz, F. (1998). Aging-related changes in processing of non-target and target stimuli during an auditory oddball task. *Biological Psychology*, *48*(3), 235–267. http://doi.org/10.1016/S0301-0511(98)00040-4

Anguera, J. a, Boccanfuso, J., Rintoul, J. L., Al-Hashimi, O., Faraji, F., Janowich, J., … Gazzaley, a. (2013). Video game training enhances cognitive control in older adults. *Nature*, *501*(7465), 97–101. http://doi.org/10.1038/nature12486

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Mariske, M., … Willis, S. L. (2002). Effects of Cognitive Training Interventions With Older Adults. *Jama*, *288*(18), 2271–2281.

Ball, K., Edwards, J.D., Ross, L.A., (2007). The impact of speed of processing training on cognitive and everyday functions. J. Gerontol.BPsychol. Sci. Soc. Sci. 62 (1), 19–31.

Basak, C., Boot, W. R., Voss, M. W., & Kramer, A. F. (2008). Can Training in a Real-Time Strategy Videogame Attenuate cognitive decline in older adults? *Psychology and Aging*, *23*(4), 765–777. http://doi.org/10.1037/a0013494.Can

Belleville, S., Mellah, S., de Boysson, C., Demonet, J.-F., & Bier, B. (2014). The pattern and loci of training-induced brain changes in healthy older adults are predicted by the nature of the intervention. *PloS One*, *9*(8), e102710. http://doi.org/10.1371/journal.pone.0102710

Berry, A. S., Zanto, T. P., Rutman, A. M., Clapp, W. C., & Gazzaley, A. (2009). Practice-related improvement in working memory is modulated by changes in processing external interference. *Journal of Neurophysiology*, *102*(3), 1779–1789. http://doi.org/10.1152/jn.00179.2009

Berryman, N., Bherer, L., Nadeau, S., Lauzire, S., Lehr, L., Bobeuf, F., … Bosquet, L. (2014). Multiple roads lead to Rome: combined high-intensity aerobic and strength training vs. gross motor activities leads to equivalent improvement in executive functions in a cohort of healthy older adults. *Age (Dordrecht, Netherlands)*, *36*(5), 9710. http://doi.org/10.1007/s11357-014-9710-8

Berti S, Geissler H, Lachmann T, Mecklinger A. (2000). Event-related brain potentials dissociate visual working memory processes under categorical and identical comparison conditions. *Cogn Brain Res, 9*, 147-155.

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., & Erickson, K. (2008). TRANSFER EFFECTS IN TASK-SET COST AND DUAL-TASK COST AFTER DUAL-TASK TRAINING IN OLDER AND YOUNGER ADULTS : FURTHER EVIDENCE FOR COGNITIVE PLASTICITY IN ATTENTIONAL CONTROL IN LATE ADULTHOOD, Experimental Aging Research, 34, 188–219. http://doi.org/10.1080/03610730802070068

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2005). Training effects on dual-task performance: are there age-related differences in plasticity of attentional control? *Psychology and Aging*, *20*(4), 695–709. http://doi.org/10.1037/0882-7974.20.4.695

Bherer, L., Kramer, A. F., Peterson, M. S., Colcombe, S., Erickson, K., & Becic, E. (2006). Testing the limits of cognitive plasticity in older adults: application to attentional control. *Acta Psychologica*, *123*(3), 261–78. http://doi.org/10.1016/j.actpsy.2006.01.005

Bier, B., de Boysson, C., & Belleville, S. (2014). Identifying training modalities to improve multitasking in older adults. *Age*, *36*(4). http://doi.org/10.1007/s11357-014-9688-2

Cabeza, R. (2002). Hemispheric asymmetry reduction in older adults: The HAROLD model. *Psychology and Aging*, *17*(1), 85–100. http://doi.org/10.1037//0882-7974.17.1.85

Cabeza, R., Grady, C. L., Nyberg, L., McIntosh, a R., Tulving, E., Kapur, S., … Craik, F. I. (1997). Age-related differences in neural activity during memory encoding and retrieval: a positron emission tomography study. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *17*(1), 391–400. http://doi.org/0270-6474/96/170391-10$05.00/0

Cocchi, L., Zalesky, A., Toepel, U., Whitford, T. J., De-Lucia, M., Murray, M. M., & Carter, O. (2011). Dynamic changes in brain functional connectivity during concurrent dual-task performance. *PLoS ONE*, *6*(11), 1–9. http://doi.org/10.1371/journal.pone.0028301

Cooper, N.R., Croft, R.J., Dominey, S.J.J., Burgess, A.P., Gruzelier, J.H., 2003. Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses. *Int. J. Psychophysiol. 47*, 65 – 74.

Craik, F.I.M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. I. M. Craik & S. Trehub (Eds.), Aging and cognitive processes (pp. 191–211). New York: Plenum.

Daffner, K. R., Chong, H., Sun, X., Tarbi, E. C., Riis, J. L., Scott, M., & Holcomb, P. J. (2012). Mechanisms Underlying Age- and Performance-related Differences in Working Memory. *J Cogn Neurosci*, *23*(6), 1298–1314. http://doi.org/10.1162/jocn.2010.21540.Mechanisms

Di Russo F, Martínez A, Hillyard S.A. (2003). Source analysis of event-related cortical activity during visuospatial attention. *Cereb Cortex. 13*:486–499.

Dixit, N. K., Gerton, B. K., Dohn, P., Meyer-Lindenberg, A., & Berman, K. F. (2000). Age-related changes in rCBF activation during an N-Back working memory paradigm occur prior to age 50. Paper presented at the Human Brain Mapping meeting, San Antonio, TX.

Drew, T.W., McCollough, A.W., & Vogel, E.K. (2006). Event-Related Potential Measures of Visual Working Memory. *Clinical EEG & Neuroscience*. 37(4), 286-291.

Duncan, J., Ward, R., Shapiro, K. (1994) Direct measurement of attentional dwell time in human vision. *Nature, 369*, 313–315

Erickson, K. I., Colcombe, S. J., Wadhwa, R., Bherer, L., Peterson, M. S., Scalf, P. E., … Kramer, A. F. (2007). Training-induced plasticity in older adults : Effects of training on hemispheric asymmetry, *28*, 272–283. http://doi.org/10.1016/j.neurobiolaging.2005.12.012

Finnigan, S., O'Connell, R. G., Cummins, T. D. R., Broughton, M., & Robertson, I. H. (2011). ERP measures indicate both attention and working memory encoding decrements in aging. *Psychophysiology*, *48*(5), 601–611. http://doi.org/10.1111/j.1469-8986.2010.01128.x

Folstein, J.R., Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: a review. *Psychophysiology 45*, 152-170

Fox, M.D., Snyder, A.Z., Vincent, J.L., Corbetta, M., Van Essen, D.C., Raichle, M.E. (2005). The human brain is intrinsically organized into dynamic, anti-correlated functional networks. *Proc. Natl. Acad. Sci. U.S.A.* 102, 9673–9678.

Foxe, J. J., & Snyder, A. C. (2011). The role of alpha-band brain oscillations as a sensory suppression mechanism during selective attention. *Frontiers in Psychology*, *2*(JUL), 1–13. http://doi.org/10.3389/fpsyg.2011.00154

Fukuda, K., & Vogel, E. K. (2009). Human Variation in Overriding Attentional Capture. *Journal of Neuroscience*, *29*(27), 8726–8733. http://doi.org/10.1523/JNEUROSCI.2145-09.2009

Gazzaley,A., Clapp, W. C.,Kelley, J.,McEvoy, K.,Knight, R. T., and D'Esposito,M. (2008). Age-related top-down suppression deficit in the early stages of cortical visual memory processing. *Proc. Natl. Acad. Sci. U.S.A. 105*, 13122–13126. doi: 10.1073/pnas.0806074105

Giacometti, P., Perdue, K. L., & Diamond, S. G. (2014). Algorithm to find high density EEG scalp coordinates and analysis of their correspondence to structural and functional regions of the brain. *Journal of Neuroscience Methods*, *229*, 84–96. http://doi.org/10.1016/j.jneumeth.2014.04.020

Glass, J. M., Schumacher, E. H., Lauber, E. J., Zurbriggen, E. L., Gmeindl, L., Kieras, D. E., & Meyer, D. E. (2000). Aging and the psychological refractory period: task-coordination strategies in young and old adults. *Psychology and Aging*, *15*(4), 571–595. http://doi.org/10.1037/0882-7974.15.4.571

Glisky, E.L. (2007). Changes in cognitive function in human aging. In D. R. Riddle (Ed.), Brain aging: Models, methods, and mechanisms (pp. 3–20). Boca Raton, FL: CRC Press.

Golomb, J.D., Nguyen-Phuc, A.Y., Mazer, J.A., McCarthy, G., Chun, M.M. (2010). Attentional facilitation throughout human visual cortex lingers in retinotopic coordinates after eye movements. *J Neurosci.* 30(31):10493-506.

Gopher, D., Armony L, Greenshpan Y. (2000). Switching tasks and attention policies. *J Exp Psychol Gen. 129*(3):308-39.

Grady, C. L., Bernstein, L. J., Beig, S., & Siegenthaler, A. L. (2002). The effects of encoding strategy on age-related changes in the functional neuroanatomy of face memory. *Psychology and Aging, 17*, 7–23.

Grady, C. L., Springer, M. V, Hongwanishkul, D., McIntosh, A. R., & Winocur, G. (2006). Age-related changes in brain activity across the adult lifespan. *Journal of Cognitive Neuroscience*, *18*(2), 227–241. http://doi.org/10.1162/089892906775783705

Guevara, M. A., & Corsi-Cabrera, M. (1996). EEG coherence or EEG correlation? *International Journal of Psychophysiology*, *23*(3), 145–153. http://doi.org/10.1016/S0167-8760(96)00038-4

Guevara, M. A., & Corsi-Cabrera, M. (1996). EEG coherence or EEG correlation? *International Journal of Psychophysiology*, *23*(3), 145–153. http://doi.org/10.1016/S0167-8760(96)00038-4

Hahn, S. and Kramer, A. F. (1995). Attentional flexibility and aging: You don’t need to be 20 years of age to split the beam. *Psychology and Aging 1*0, 597–609.

Hartley, A. A., Jonides, J., & Sylvester, C. C. (2011). Brain and Cognition Dual-task processing in younger and older adults : Similarities and differences revealed by fMRI. *Brain and Cognition*, *75*(3), 281–291. http://doi.org/10.1016/j.bandc.2011.01.004

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension and aging: A review and a new view. *Psychology of Learning and Motivation, 22*, 193–225.

Hazeltine, E., Teague, D., & Ivry, R. B. (2002). Simultaneous dual-task performance reveals parallel response selection after practice. *Journal of Experimental Psychology: Human Perception and Performance*, *28*(3), 527–545. http://doi.org/10.1037/0096-1523.28.3.527

Herath, P., Klingberg, T., Young, J., Amunts, K., & Roland, P. (2001). Neural correlates of dual task interference can be dissociated from those of divided attention: an fMRI study. *Cerebral Cortex (New York, N.Y. : 1991)*, *11*(9), 796–805. http://doi.org/10.1093/cercor/11.9.796

Hertzog, C., Kramer, A. F., Wilson, R. S., & Lindenberger, U. (2009). Enrichment Effects on Adult Cognitive Development. *Psychological Science, 9*(1), 1–65. http://doi.org/10.1111/j.1539-6053.2009.01034.x

Ho, M.-C., Chou, C.-Y., Huang, C.-F., Lin, Y.-T., Shih, C.-S., Han, S.-Y., … Liu, C.-J. (2012). Age-related changes of task-specific brain activity in normal aging. *Neuroscience Letters*, *507*(1), 78–83. http://doi.org/10.1016/j.neulet.2011.11.057

Hummel, F., & Gerloff, C. (2005). Larger interregional synchrony is associated with greater behavioral success in a complex sensory integration task in humans. *Cerebral Cortex*, *15*(5), 670–678. http://doi.org/10.1093/cercor/bhh170

Jaeggi, S. M., Buschkuehl, M., Jonides, J., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(19), 6829–6833. http://doi.org/10.1073/pnas.0801268105

Jasper, H. H. (1958). The ten-twenty electrode system of the international federation Electroencephalography and Clinical Neurophysiology, 10, 371-558

Jennings, J.R. and Wood, C.C. (1976). The c-adjustment procedure for repeated-measures analyses of variance. *Psychophysiology, 13*: 277-278.

Kardos, Z., Toth, B., Boha, R., File, B., & Molnar, M. (2014). Age-related changes of frontal-midline theta is predictive of efficient memory maintenance. *Neuroscience*, *273*, 152–162. http://doi.org/10.1016/j.neuroscience.2014.04.071

Kawasaki, M., Kitajo, K., & Yamaguchi, Y. (2010). Dynamic links between theta executive functions and alpha storage buffers in auditory and visual working memory. *European Journal of Neuroscience*, *31*(9), 1683–1689. http://doi.org/10.1111/j.1460-9568.2010.07217.x

Khadem, A., & Hossein-Zadeh, G.-A. (2014). Quantification of the effects of volume conduction on the EEG/MEG connectivity estimates: an index of sensitivity to brain interactions. *Physiological Measurement*, *35*(10), 2149–64. http://doi.org/10.1088/0967-3334/35/10/2149

Kida, T., Kaneda, T., & Nishihira, Y. (2012). Dual-task repetition alters event-related brain potentials and task performance. *Clinical Neurophysiology*, *123*(6), 1123–1130. http://doi.org/10.1016/j.clinph.2011.10.001

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis. *Brain Research Reviews*, *29*(2-3), 169–195. http://doi.org/10.1016/S0165-0173(98)00056-3

Klimesch, W., Vogt, F., Doppelmayr, M. (1999). Interindividual differences in alpha and theta power reflect memory performance. *Intelligence, 4*, 347–362.

Klingberg, T. (2006). Development of a superior frontal-intraparietal network for visuo-spatial working memory. *Neuropsychologia*, *44*(11), 2171–2177. http://doi.org/10.1016/j.neuropsychologia.2005.11.019

Kopp, F., Schroger, E., & Lipka, S. (2004). Neural networks engaged in short-term memory rehearsal are disrupted by irrelevant speech in human subjects. *Neuroscience Letters*, *354*(1), 42–45. http://doi.org/10.1016/j.neulet.2003.09.065

Kramer, A. F., Hahn, S., & Gopher, D. (1999). Task coordination and aging: explorations of executive control processes in the task switching paradigm. *Acta Psychologica*, *101*(2-3), 339–378. http://doi.org/10.1016/S0001-6918(99)00011-6

Kramer, A. F., Larish, J. F., & Strayer, D. L. (1995). Training for attentional control in dual task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied*, *1*(1), 50–76. http://doi.org/10.1037/1076-898X.1.1.50

Krause, B. J., Hautzel, H., Schmidt, D., Flüß, M. O., Poeppel, T. D., Müller, H. W., … Mottaghy, F. M. (2006). Learning related interactions among neuronal systems involved in memory processes. *Journal of Physiology Paris*, *99*(4-6), 318–332. http://doi.org/10.1016/j.jphysparis.2006.03.017

Lampit, A., Ebster, C., & Valenzuela, M. (2014). performance of bookkeeping tasks : a matched-sampling active-controlled Multi-domain computerized cognitive training program improves performance of bookkeeping tasks : a matched-sampling active- controlled trial, *5*(July), 1–7. http://doi.org/10.3389/fpsyg.2014.00794

Lavie, N. (1995) Perceptual load as a necessary condition for selective attention. J. Exp. Psychol. Hum. Percept. Perform. 21, 451–468

Lefebvre, C. D., Marchand, Y., Eskes, G. A., & Connolly, J. F. (2005). Assessment of working memory abilities using an event-related brain potential (ERP)-compatible digit span backward task. Clinical Neurophysiology, 116, 1665–1680.

Looren de Jong, H., Kok, A. and Van Rooy, J.C.G.M. (1988). Early and late selection in young and old adults: an event-related potential study. Psychophysiology, 25: 657-671.

Luck, S. J., Woodman, G. F., & Vogel, E. K. (2000). Event-related potential studies of attention. *Trends in Cognitive Sciences*, *4*(11), 432–440. http://doi.org/10.1016/S1364-6613(00)01545-X

Lussier, M., Brouillard, P., & Bherer, L. (2015). Limited Benefits of Heterogeneous Dual-Task Training on Transfer Effects in Older Adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *00*(00), gbv105. http://doi.org/10.1093/geronb/gbv105

Lustig, C., Snyder, A. Z., Bhakta, M., O'Brien, K. C., McAvoy, M., Raichle, M. E., … Buckner, R. L. (2003). Functional deactivations: change with age and dementia of the Alzheimer type. *Proc Natl Acad Sci U S A*, *100*(24), 14504–14509. http://doi.org/10.1073/pnas.2235925100\r2235925100 [pii]

Malcolm, B. R., Foxe, J. J., Butler, J. S., & De Sanctis, P. (2015). The aging brain shows less flexible reallocation of cognitive resources during dual-task walking: A mobile brain/body imaging (MoBI) study. *NeuroImage*, *117*, 230–42. http://doi.org/10.1016/j.neuroimage.2015.05.028

Maquestiaux, F., Hartley, A.A., & Bertsch, J. (2004). Can practice overcome age-related differences in the psychological refractory period effect. Psychology & Aging, 19(4), 649-667.

Marklund, P., Fransson, P., Cabeza, R., Petersson, K. M., Ingvar, M., & Nyberg, L. (2007). Sustained and transient neural modulations in prefrontal cortex related to declarative long-term memory, working memory, and attention. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *43*(1), 22–37. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/17334205

Marois, R., & Ivanoff, J. (2005). Capacity limits of information processing in the brain. *Trends Cogn Sci*, *9*(6), 296–305.

Martin, A.J., Friston, K.J., Colebatch, J.G., Frackowiak, R.S. (1991). Decreases in regional cerebral blood flow with normal aging. *J. Cereb. Blood Flow Metab*. 11, 684–689.

McEvoy, L. K., Pellouchoud, E., Smith, M. E., & Gevins, A. (2001). Neurophysiological signals of working memory in normal aging. *Cognitive Brain Research*, *11*(3), 363–376. http://doi.org/10.1016/S0926-6410(01)00009-X

Mecklinger, A., & Pfeifer, E. (1996). Event-related potentials reveal topographical and temporal distinct neuronal activation patterns for spatial and object working memory. *Cognitive Brain Research*, *4*(3), 211–224. http://doi.org/10.1016/S0926-6410(96)00034-1

Meiran, N., Gotler, A., & Perlman, A. (2001). Old Age Is Associated With a Pattern of Relatively Intact and Relatively Impaired Task-Set Switching Abilities. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *56*(2), P88–P102. http://doi.org/10.1093/geronb/56.2.P88

Miller, E.K., Cohen J.D. (2001). An integrative theory of prefrontal cortex function. Annu Rev Neurosci:167–202.

Mishra, J., Rolle, C., & Gazzaley, A. (2015). Neural plasticity underlying visual perceptual learning in aging. *Brain Research*, *1612*, 140–151. http://doi.org/10.1016/j.brainres.2014.09.009

Moeller, J. R., Ishikawa, T., Dhawan, V., Spetsieris, P., Mandel, F., Alexander, G. E., … Eidelberg, D. (1996). The metabolic topography of normal aging. *Journal of Cerebral Blood Flow and Metabolism : Official Journal of the International Society of Cerebral Blood Flow and Metabolism*, *16*, 385–398. http://doi.org/10.1097/00004647-199605000-00005

Mozolic, J. L., Long, A. B., Morgan, A. R., Rawley-Payne, M., & Laurienti, P. J. (2011). A cognitive training intervention improves modality-specific attention in a randomized controlled trial of healthy older adults. *Neurobiology of Aging*, *32*(4), 655–68. http://doi.org/10.1016/j.neurobiolaging.2009.04.013

Nasreddine, Z. S., Phillips, N. a., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., … Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society*, *53*, 695–699. http://doi.org/10.1111/j.1532-5415.2005.53221.x

Navon, D., & Miller, J. (1987). Role of Outcome Conflict in Dual-Task Interference, *Journal of Experimental Psychology*, *13*(3), 435-448.

Nino, R. S., & Rickard, T. C. (2003). Practice effects on two memory retrievals from a single cue. Journal of Experimental Psychology: Learning, Memory, and Cognition, 29, 373–388.

Nyberg, L., Sandblom, J., Jones, S., Neely, A. S., Petersson, K. M., Ingvar, M., & Ba, L. (2003). Neural correlates of training-related memory improvement in adulthood and aging.

Oberauer, K., & Kliegl, R. (2004). Simultaneous cognitive operations in working memory after dual-task practice. Journal of Experimental Psychology. *Human Perception and Performance*, 30(4), 689–707. http://doi.org/10.1037/0096-1523.30.4.689

Olesen, P. J., Westerberg, H., & Klingberg, T. (2004). Increased prefrontal and parietal activity after training of working memory. *Nature Neuroscience*, *7*(1), 75–9. http://doi.org/10.1038/nn1165

Onton, J., Delorme, A., & Makeig, S. (2005). Frontal midline EEG dynamics during working memory. *NeuroImage*, *27*(2), 341–356. http://doi.org/10.1016/j.neuroimage.2005.04.014

Papp, K. V, Walsh, S. J., & Snyder, P. J. (2009). Immediate and delayed effects of cognitive interventions in healthy elderly: a review of current literature and future directions. *Alzheimer's & Dementia : The Journal of the Alzheimer's Association*, *5*(1), 50–60. http://doi.org/10.1016/j.jalz.2008.10.008

Park, D.C., & Schwarz, N. (Eds.). (2000). *Cognitive aging: A primer*. Philadelphia: Psychology Press.

Pashler, H. E. (1998). The psychology of attention. Cambridge, MA: MIT Press.

Pinal, D., & Díaz, F. (2015). Age-related changes in brain activity are specific for high order cognitive processes during successful encoding of information in working memory, *7*(May), 1–11. http://doi.org/10.3389/fnagi.2015.00075

Plank, M. (2013). Ocular Correction ICA. Brain Products Press Release. 49: 1-4. Obtained from www.brainproducts.com on 09/05/2016.

Raghavachari S, Lisman JE, Tully M, Madsen JR, Bromfield EB, Kahana MJ. Theta oscillations in human cortex during a working-memory task: evidence for local generators. J Neurophysiol 2006;95:1630–8.

Raichle, M.E., MacLeod, A.M., Snyder, A.Z., Powers, W.J., Gusnard, D.A., Shulman, G.L. (2001). A default mode of brain function. *Proc. Natl. Acad. Sci. U.S.A. 98*, 676–682.

Rebok, G., Ball, K., Guey, L. et al. (2014). Ten-year effects of the ACTIVE cognitive training trial on cognition and everyday functioning in older adults. *Journal of the …*, *62*(1), 16–24. http://doi.org/10.1111/jgs.12607.

Reichert, J. L., Kober, S. E., Witte, M., Neuper, C., & Wood, G. (2016). Age-related effects on verbal and visuospatial memory are mediated by theta and alpha II rhythms. *International Journal of Psychophysiology*, *99*, 67–78. http://doi.org/10.1016/j.ijpsycho.2015.11.004

Reijnders, J., van Heugten, C., & van Boxtel, M. (2013). Cognitive interventions in healthy older adults and people with mild cognitive impairment: a systematic review. *Ageing Research Reviews*, *12*(1), 263–75. http://doi.org/10.1016/j.arr.2012.07.003

Renaud, M., Maquestiaux, F., Joncas, S., Kergoat, M.J., & Bherer, L. (2010). The effect of three months of aerobic training on response preparation in older adults. *Front Aging Neurosci* 2: 148. doi:10.3389/fnagi.2010.00148

Reuter-Lorenz, P.A., Lustig, C. (2005). Brain aging: Reorganizing discoveries about the aging mind. *Current Opinion in Neurobiology. 15*:245–251. [PubMed: 15831410]

Reuter-Lorenz, P.A., Stanczak, L., & Miller, A.C. (1999). Neural recruitment and cognitive aging: Two hemispheres are better than one, especially as you age. *Psychological Science, 10*, 494–500.

Roenker, D.L., Cissell, G.M., Ball, K.,Wadley, V.G., Edwards, J.D. (2003). Speed of processing and driving simulator training result in improved driving performance. *Hum Factors, 45*:218–32.

Rogers, W.A., Bertus, E. L., & Gilbert, D.K. (1994). Dual-Task Assessment of Age-Differences in Automatic Process-Development. *Psychology and Aging*, *9*(3), 398–413.

Ruchkin, D. S., Johnson, R., Canoune, H., & Ritter, W. (1990). Short-term memory storage and retention: an event-related brain potential study. *Electroencephalography and Clinical Neurophysiology*, *76*(5), 419–439. http://doi.org/10.1016/0013-4694(90)90096-3

Ruchkin, D. (2005). EEG coherence. *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology*, *57*(2), 83–5. http://doi.org/10.1016/j.ijpsycho.2005.04.001

Ruchkin, D.S., Canoune, H.L., Johnson, R., & Ritter, W. (1995). Working memory and preparation elicit different patterns of slow wave event-related brain potentials. *Psychophysiology*, *32*(4), 399–410. http://doi.org/10.1111/j.1469-8986.1995.tb01223.x

Rypma, B., & D'Esposito, M. (2000). Isolating the neural mechanisms of age-related changes in human working memory. Nature Neuroscience, 3, 509–515.

Salthouse, T.A., Rogan, J.D., & Prill, K.A. (1984). Division of attention: Age differences on a visually presented memory task. Memory & Cognition, 12(6), 613-20.

Salthouse, T.A., Fristoe, N. M., Lineweaver, T. T., & Coon, V. E. (1995). Aging of attention: does the ability to divide decline? *Memory & Cognition*, *23*(1), 59–71. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7885266

Salthouse, T. A. (1996). The processing speed theory of adult age differences in cognition. *Psychological Review, 103*, 403–428.

Sarnthein, J., Petsche, H., Rappelsberger, P., Shaw, G. L., & Von Stein, A. (1998). Synchronization between prefrontal and posterior association cortex during human working memory. *Proceedings of the National Academy of Sciences of the United States of America*, *95*(12), 7092–7096. http://doi.org/10.1073/pnas.95.12.7092

Sauseng, P., & Klimesch, W. (2008). What does phase information of oscillatory brain activity tell us about cognitive processes? *Neuroscience and Biobehavioral Reviews*, *32*(5), 1001–13. http://doi.org/10.1016/j.neubiorev.2008.03.014

Sauseng, P., Hoppe, J., Klimesch, W., Gerloff, C. & Hummel, F.C. (2007). Dissociation of sustained attention from central executive functions: local activity and interregional connectivity in the theta range. *Eur. J.Neurosci., 25*, 587–593.

Sauseng, P., Klimesch, W., Freunberger, R., Pecherstorfer, T., Hanslmayr, S., & Doppelmayr, M. (2006). Relevance of EEG alpha and theta oscillations during task switching. *Experimental Brain Research*, *170*(3), 295–301. http://doi.org/10.1007/s00221-005-0211-y

Sauseng, P., Klimesch, W., Schabus, M., & Doppelmayr, M. (2005). Fronto-parietal EEG coherence in theta and upper alpha reflect central executive functions of working memory. *International Journal of Psychophysiology*, *57*(2), 97–103. http://doi.org/10.1016/j.ijpsycho.2005.03.018

Scheeringa, R., Bastiaansen, M. C. M., Petersson, K. M., Oostenveld, R., Norris, D. G., & Hagoort, P. (2008). Frontal theta EEG activity correlates negatively with the default mode network in resting state. *International Journal of Psychophysiology*, *67*(3), 242–251. http://doi.org/10.1016/j.ijpsycho.2007.05.017

Schmidt, R.A., & Bjork, R.A. (1992). New Conceptualizations of Practice: Common Principles in Three Paradigms Suggest New Concepts for Training. *Psychological Science*, *3*(4), 207–217. http://doi.org/10.1111/j.1467-9280.1992.tb00029.x

Schubert, T., & Szameitat, A. J. (2003). Functional neuroanatomy of interference in overlapping dual tasks: An fMRI study. *Cognitive Brain Research*, *17*(3), 733–746. http://doi.org/10.1016/S0926-6410(03)00198-8

Schumacher, E. H., Seymour, T. L., Glass, J. M., Kieras, D. E., & Meyer, D. E. (2001). Virtually perfect time sharing in dual-task performance: Uncorking the central attentional bottleneck. *Psychological Science, 12*, 101–108.

Schurmann, M., Basar-Eroglu, C., Basar, E. (1997). A possible role of evoked alpha in primary sensory processing: common properties of cat intracranial recordings and human EEG and MEG. *Int J Psychophysiol, 26*:149--170.

Sekuler, R., McLaughlin, C., & Yotsumoto, Y. (2008). Age-related changes in attentional tracking of multiple moving objects. *Perception*, *37*(6), 867–876. http://doi.org/10.1068/p5923

Somberg, L., & Salthouse, T.A. (1982). Divided attention abilities in young and old adults. Journal of Experimental Psychology: *Human Perception & Performance, S*, 651-663.

Strayer, D.L., & Drews, F.A. (2004). Profiles in driver distraction: effects of cell phone conversations on younger and older drivers. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *46*(4), 640–649. http://doi.org/10.1518/hfes.46.4.640.56806

Trick, L.M., Perl, T., & Sethi, N. (2005). Age-related differences in multiple-object tracking. *Journal of Gerontology: Psychological Sciences*, *60*(2), 102–105. http://doi.org/10.1093/geronb/60.2.P102

Tsang, P.S., & Shaner, T.L. (1998). Age, attention, expertise, and time-sharing performance. *Psychology and Aging, 13*, 323–347.

Verhaeghen, P., Steitz, D., Sliwinski, M., & Cerella, J. (2003). Aging and dual-task performance: a meta-analysis. *Psychology and Aging, 18(3)*, 443-460.

Vogel, E. K., & Luck, S. J. (2000). The visual N1 component as an index of a discrimination process. *Psychophysiology*, *37*(2), 190–203. http://doi.org/10.1111/1469-8986.3720190

Wahn, B., & König, P. (2016). Attentional Resource Allocation in Visuotactile Processing Depends on the Task , But Optimal Visuotactile Integration Does Not Depend on Attentional Resources. *Frontiers in Integrative Neuroscience, 10*(March), 1–13. http://doi.org/10.3389/fnint.2016.00013

Wascher, E., Rasch, B., Sanger, J., Hoffmann, S., Schneider, D., Rinkenauer, G., … Gutberlet, I. (2014). Frontal theta activity reflects distinct aspects of mental fatigue. *Biological Psychology*, *96*(1), 57–65. http://doi.org/10.1016/j.biopsycho.2013.11.010

Wechsler D (1997) WAIS-III: Wechsler adult intelligence scale: Psychological Corporation San Antonio.

White, T. P., Jansen, M., Doege, K., Mullinger, K. J., Park, S. B., Liddle, E. B., … Liddle, P. F. (2013). Theta power during encoding predicts subsequent-memory performance and default mode network deactivation. *Human Brain Mapping*, *34*(11), 2929–2943. http://doi.org/10.1002/hbm.22114

Wiegand, I., Töllner, T., Dyrholm, M., Müller, H. J., Bundesen, C., & Finke, K. (2014). Neural correlates of age-related decline and compensation in visual attention capacity. *Neurobiology of Aging*, *35*(9), 2161–73. http://doi.org/10.1016/j.neurobiolaging.2014.02.023

Wiegand, I., Töllner, T., Dyrholm, M., Müller, H. J., Bundesen, C., & Finke, K. (2014). Neural correlates of age-related decline and compensation in visual attention capacity. *Neurobiology of Aging*, *35*(9), 2161–73.

Wolfe, J.M. (1994) Guided search 2.0: a revised model of visual search. *Psychonomic Bull. Rev. 1*, 202–238

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait and Posture*, *16*(1), 1–14. http://doi.org/10.1016/S0966-6362(01)00156-4

Yesavage, J. A. (1988). Geriatric Depression Scale. *Psychopharmacological Bulletin, 24*, 709.

Yesavage, J., Hoblyn, J., Friedman, L., Mumenthaler, M., Schneider, B., & Hara, R. O. (2007). Should One Use Medications in Combination With Cognitive Training? If So, Which Ones?, *Journal of Gerontology, 62(*I), 11–18.

Zanto, T.P., Toy, B., and Gazzaley, A. (2010). Delays in neural processing during working memory encoding in normal aging. *Neuropsychologia, 48*, 13–25.

Table 1.

Demographic information for study participants. All values are mean (SD). P-values for Age and Education are based on separate univariate ANOVAs, while the %Female p-value was obtained for the Pearson Chi-Square test.

Group	Age (years)	Education (years)	%Female
STT (N=13)	68.97(7.97)	14.69(3.25)	76.92
FAT (N=12)	70.68(6.82)	14.92(2.54)	58.33
VAT (N=14)	68.43(4.99)	15.43(3.98)	64.29
p-value	>0.05	>0.05	>0.05

Table 2.

Significant effects of coherence in the 80-200 ms post-stimulus time period. Additional significant effects are reported in the text.

Frequency	Electrode Pair Family	Effect	Df (1, 2)	F	p-value	ηp^2	E
	Midline	-	-	-	-	-	-
	Longitudinal Left	(Dual-task 50/50) Electrode Pair	(3, 105)	13.19	<0.001	0.27	0.44
		(Dual-task 50/50) Condition x Electrode Pair	(6, 210)	5.08	<0.005	0.13	0.43

Frequency	Electrode Pair Family	Effect	Df (1, 2)	F	p-value	ηp^2	E
Alpha		(Dual-task 20/80) Condition x Electrode Pair	(6, 210)	3.45	P<0.05	0.09	0.43
		(Dual-task 50/50) Electrode Pair	(3, 105)	63.23	<0.001	0.64	0.59
	Longitudinal Right	(Dual-task 50/50) Groups x Electrode Pair	(6, 105)	2.79	<0.05	0.14	0.59
		(Dual-task 50/50) Condition x Electrode Pair	(6, 210)	3.31	<0.05	0.09	0.61
		(Dual-task 20/80) Electrode Pair	(3, 105)	56.63	<0.001	0.62	0.54
		(Dual-task 20/80) Groups x Condition x Electrode Pair	(12, 210)	2.68	<0.05	0.13	0.61
Theta	Midline	(Dual-task 50/50) Electrode Pair	(3, 105)	3.74	<0.05	0.096	0.696
		(Dual-task 20/80) Electrode Pair	(3, 105)	6.94	=0.001	0.17	0.75
	Longitudinal Left	(Dual-task 20/80) Electrode Pair	(3, 105)	7.31	<0.001	0.17	0.88
		(Dual-task 20/80) Electrode Pair	(3, 105)	5.697	<0.01	0.14	0.76
	Longitudinal Right	(Dual-task 50/50) Electrode Pair	(3, 105)	7.73	<0.001	0.18	0.84
		(Dual-task 20/80) Electrode Pair	(3, 105)	9.20	<0.001	0.21	0.72

Table 3.

Significant effects of coherence in the 800-950 ms post-stimulus time period. Additional significant effects are reported in the text.

Alpha	Midline	None	-	-	-	-	-
	Longitudinal Left	(Dual-task 50/50) Electrode Pair	(3, 105)	72.73	<0.001	0.68	0.83
		(Dual-task 20/80) Electrode Pair	(3, 105)	69.44	<0.001	0.67	0.48
	Longitudinal Right	(Dual-task 50/50) Electrode Pair	(3, 105)	71.23	<0.001	0.67	0.67
		(Dual-task 20/80) Electrode Pair	(3, 105)	73.36	<0.001	0.68	0.69
Theta	Midline	(Dual-task 20/80) Condition x Electrode Pair	(6, 210)	3.40	P<0.05	0.09	0.46
	Longitudinal Left	(Dual-task 50/50) Electrode Pair	(3, 105)	53.94	<0.001	0.61	0.65
		(Dual-task 20/80) Electrode Pair	(3, 105)	63.61	<0.001	0.65	0.60
	Longitudinal Right	(Dual-task 50/50) Electrode Pair	(3, 105)	54.51	<0.001	0.61	0.74
		(Dual-task 20/80) Electrode Pair	(3, 105)	65.86	<0.001	0.65	0.74

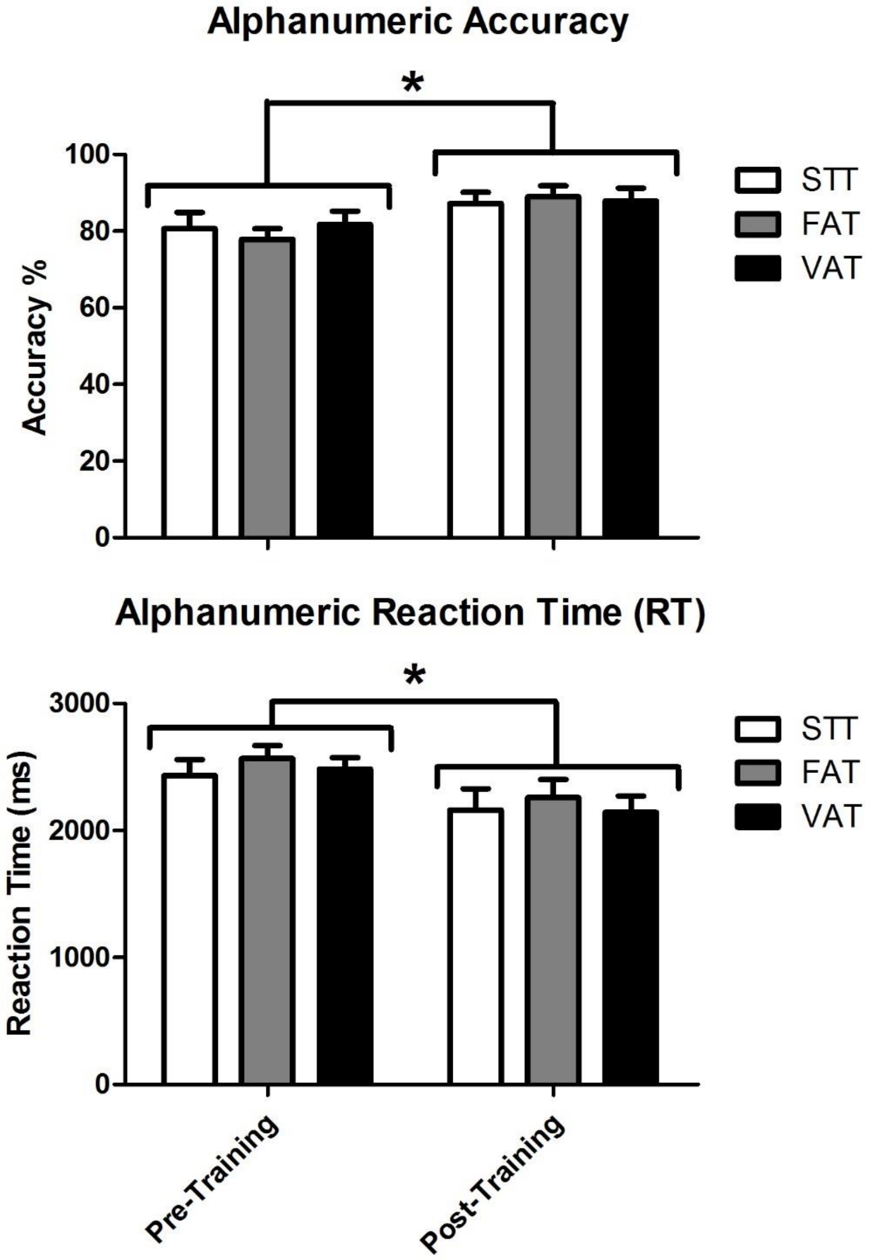


Figure 1. Accuracy (%) and reaction time (ms) for participants performing the single alphanumeric equation task. STT, Single Task Training; FAT, Fixed Attention Training; VAT, Variable Attention Training. Error bars represent standard error. * $p<0.05$.

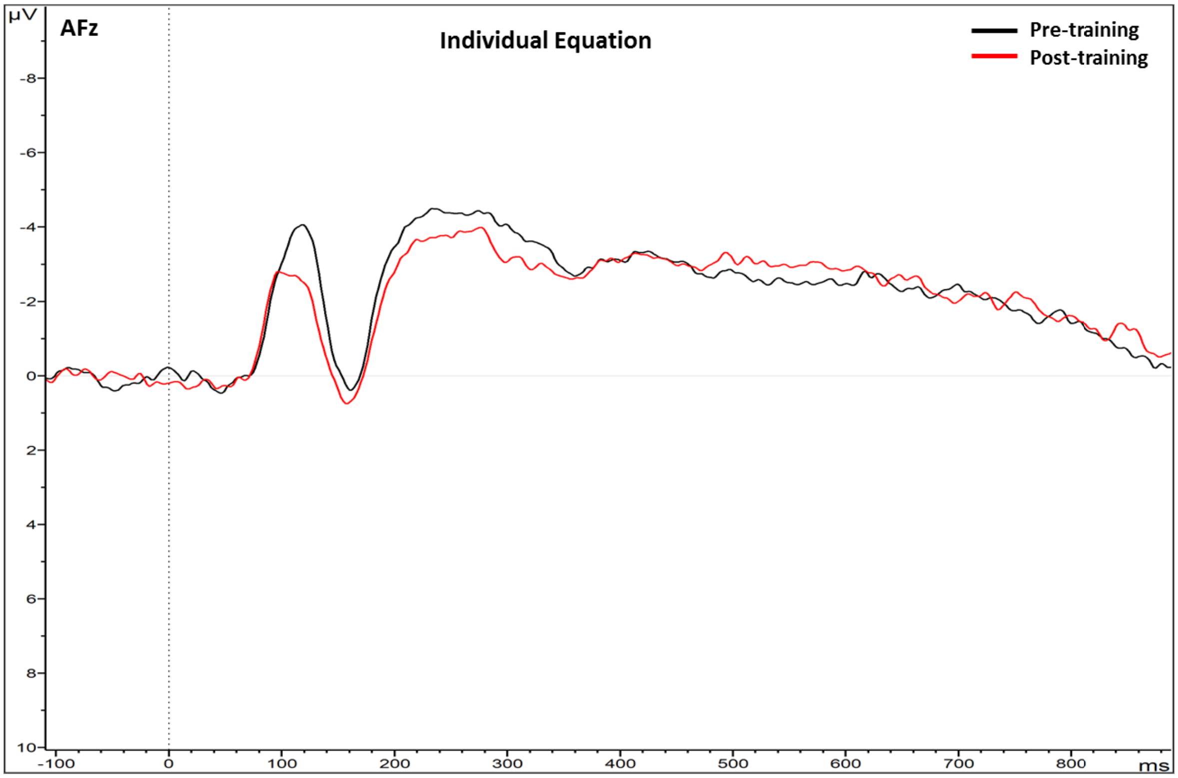


Figure 2. Grand average waveform at electrode site AFz for participants performing the individual alphanumeric equation task. The N1-P2 complex is visible from approximately 100 to 200 ms post-stimulus, followed by a sustained negativity from 300 to 750 ms that gradually returned to baseline. Black line, pre-training; red line, post-training.

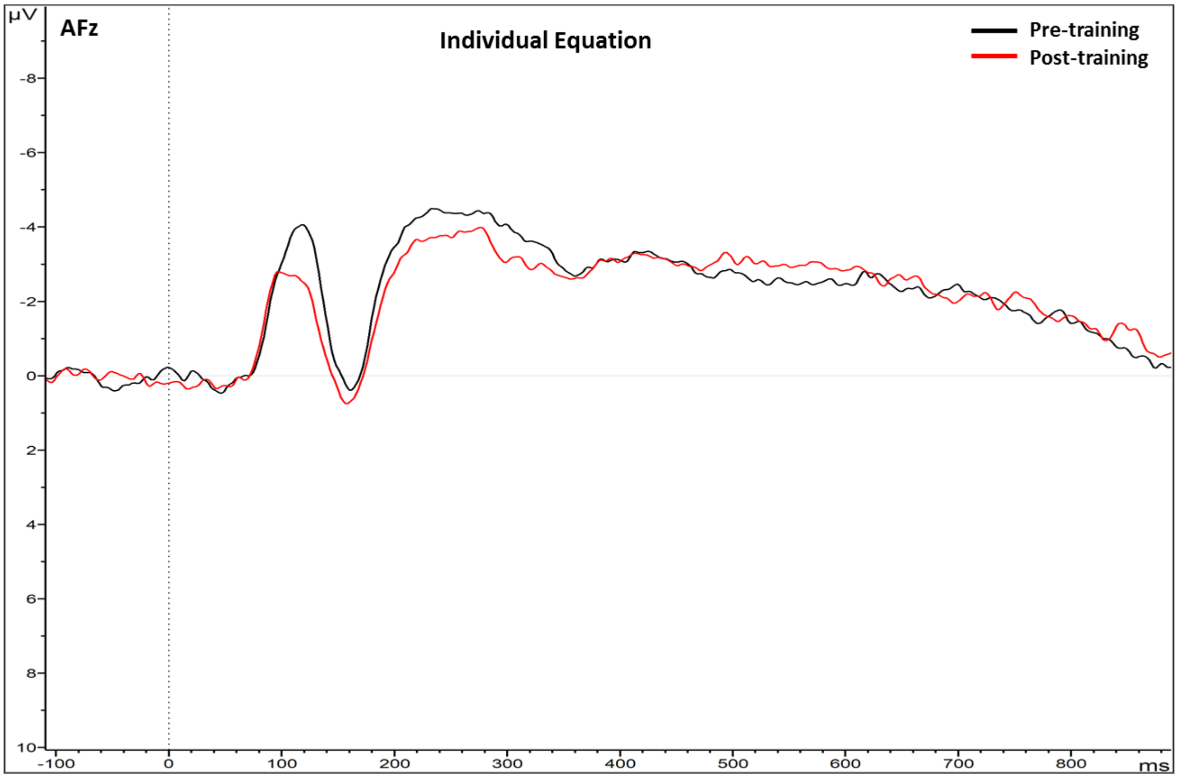


Figure 2. Grand average waveform at electrode site AFz for participants performing the individual alphanumeric equation task. The N1-P2 complex is visible from approximately 100 to 200 ms post-stimulus, followed by a sustained negativity from 300 to 750 ms that gradually returned to baseline. Black line, pre-training; red line, post-training.

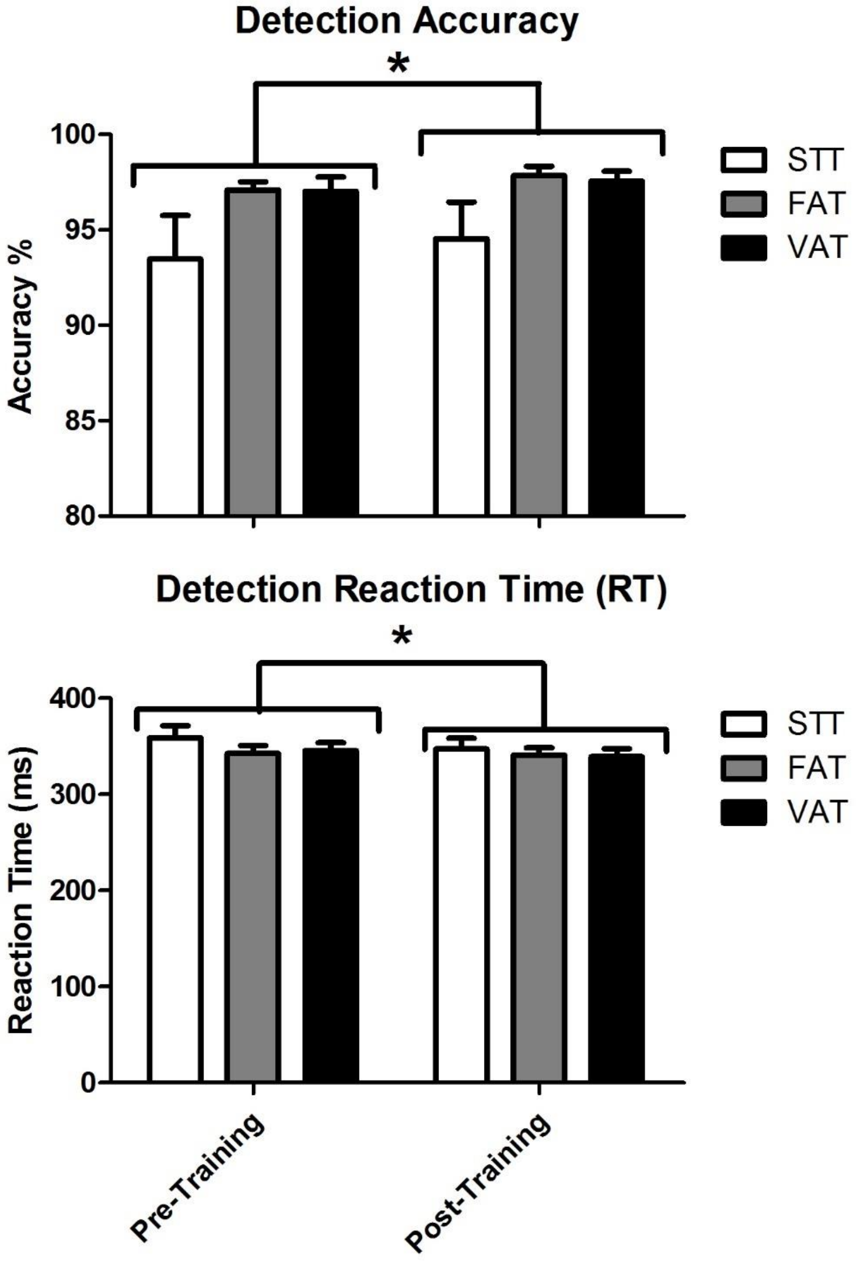


Figure 3. Accuracy (%) and reaction time (ms) for participants performing the single visual detection task. STT, Single Task Training; FAT, Fixed Attention Training; VAT, Variable Attention Training. Error bars represent standard error. * $p<0.05$.

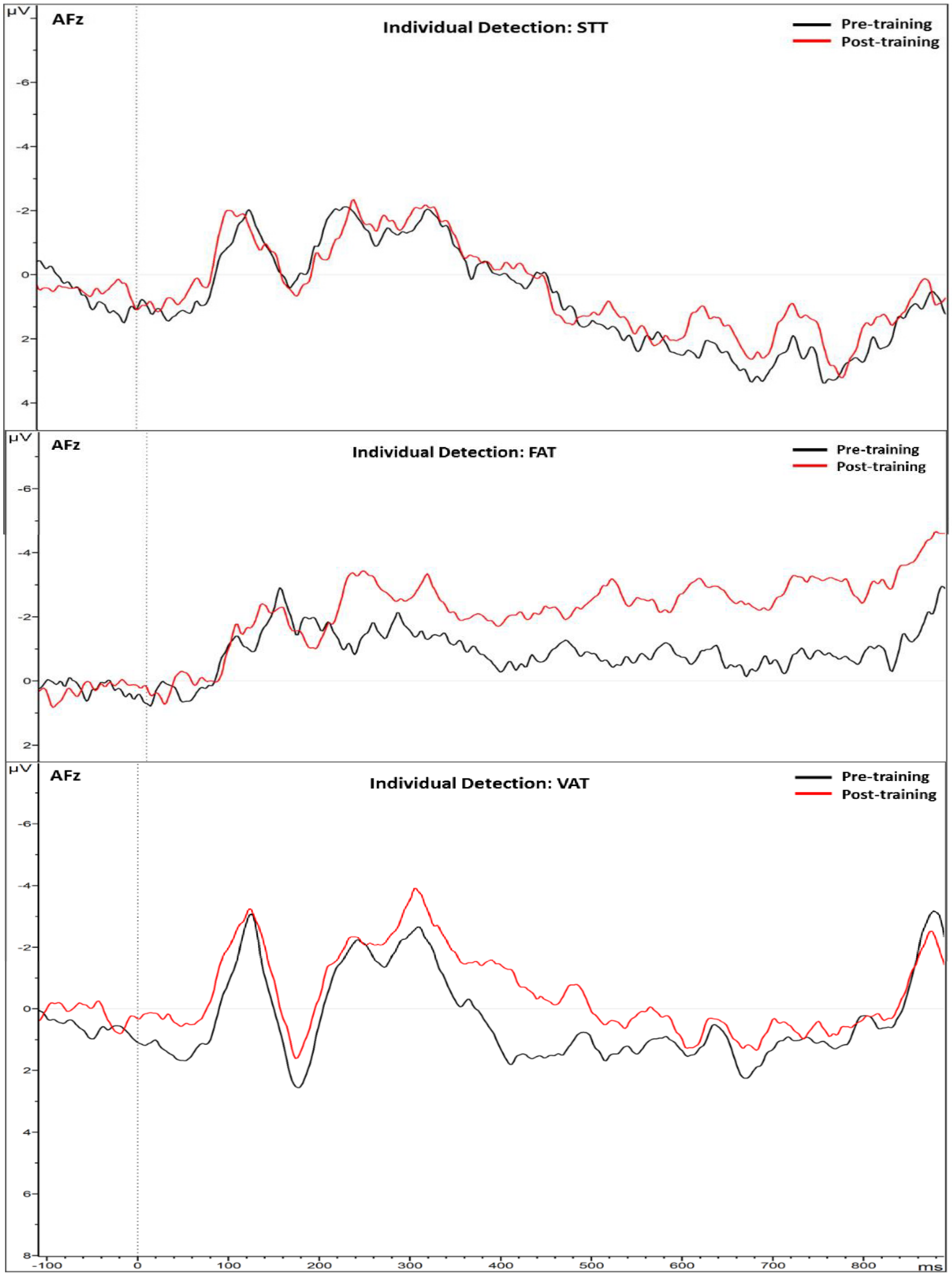


Figure 4: Grand average waveforms at electrode site AFz for participants performing the individual visual detection task. The N1-P2 complex is visible from approximately 100 to 200 ms post-stimulus, followed by a sustained negativity from 300 to 750 ms that gradually returned to baseline. Top panel: Single Task Training (STT) group; Middle panel: Fixed Attention Training (FAT); Bottom panel: Variable Attention Training (VAT) group. Black line, pre-training; red line, post-training.

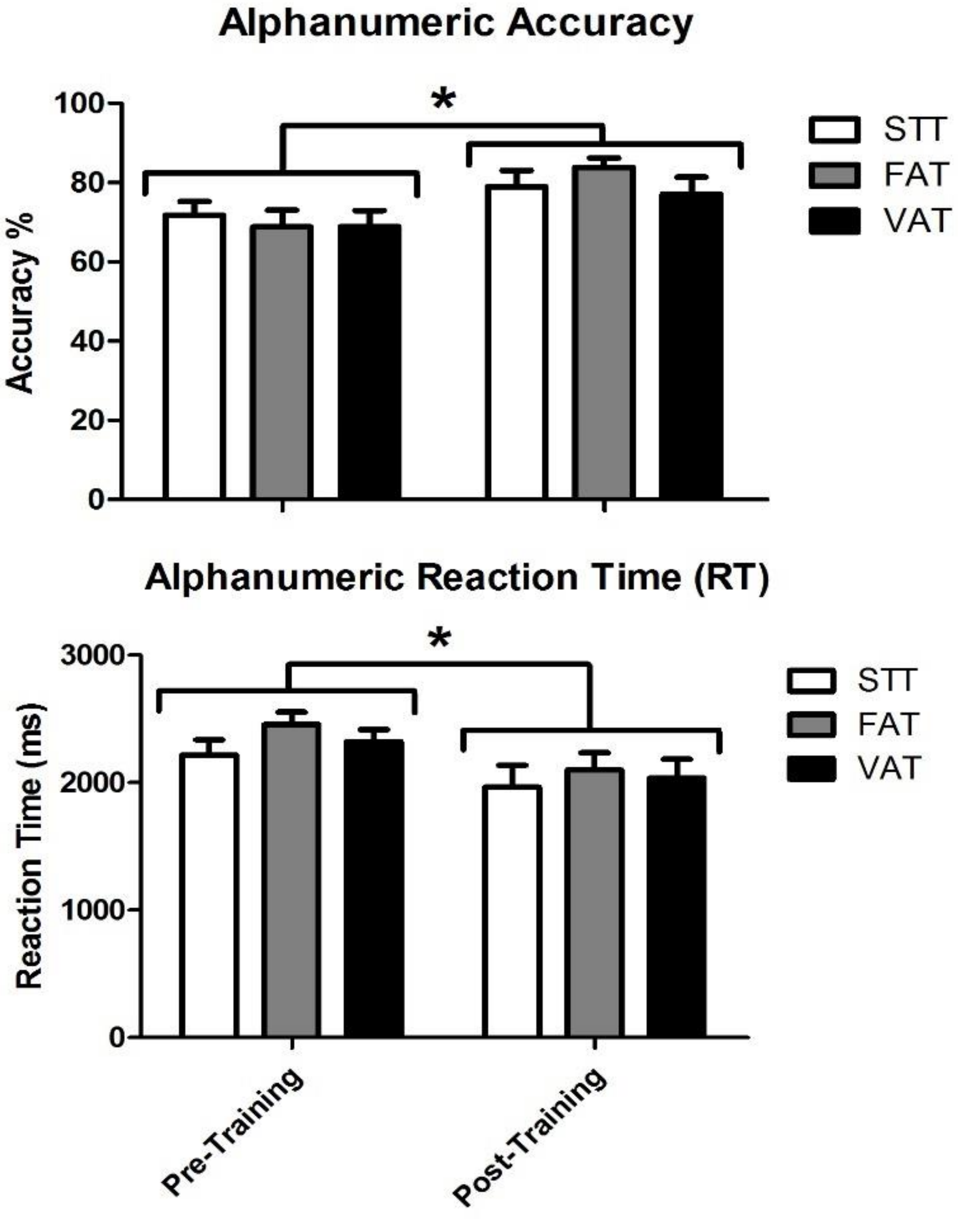


Figure 5. Accuracy (%) and reaction time (ms) for participants performing the alphanumeric equation task during the Dual-task 50/50 condition. STT, Single Task Training; FAT, Fixed Attention Training; VAT, Variable Attention Training. Error bars represent standard error. * $p<0.05$.

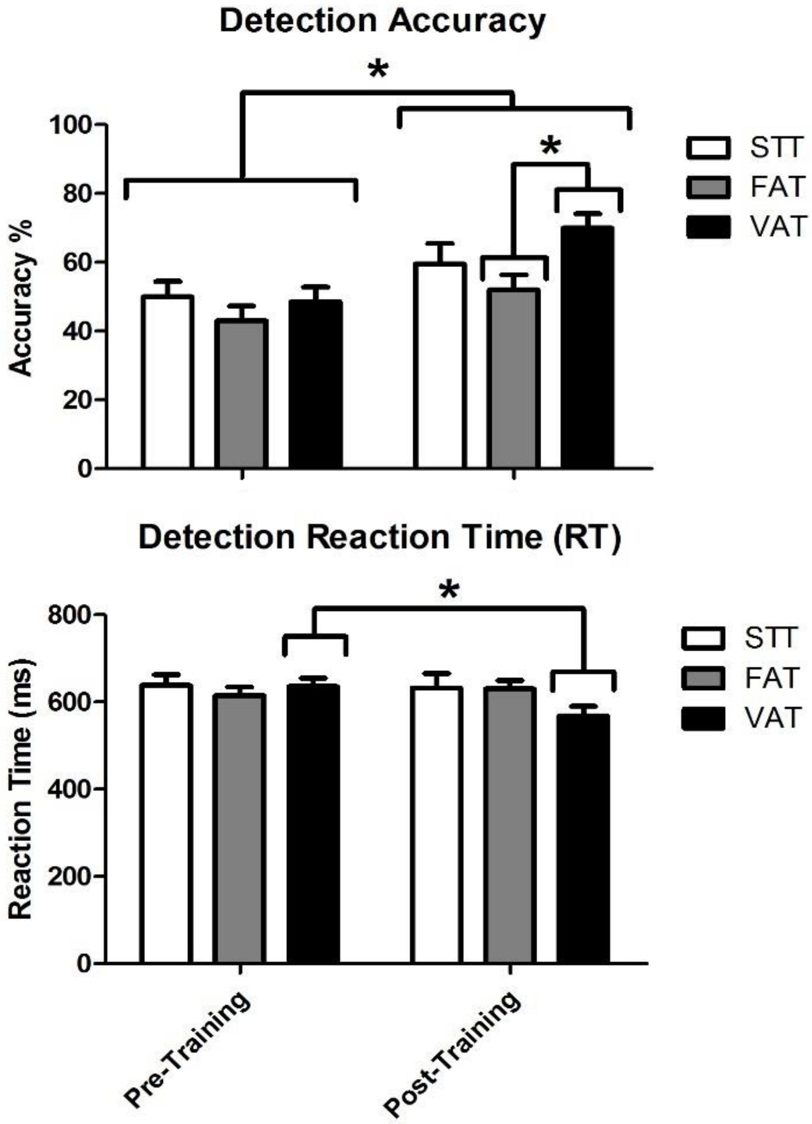


Figure 6. Accuracy (%) and reaction time (ms) for participants performing the visual detection task during the Dual-task 50/50 condition. STT, Single Task Training; FAT, Fixed Attention Training; VAT, Variable Attention Training. Error bars represent standard error. * $p<0.05$.

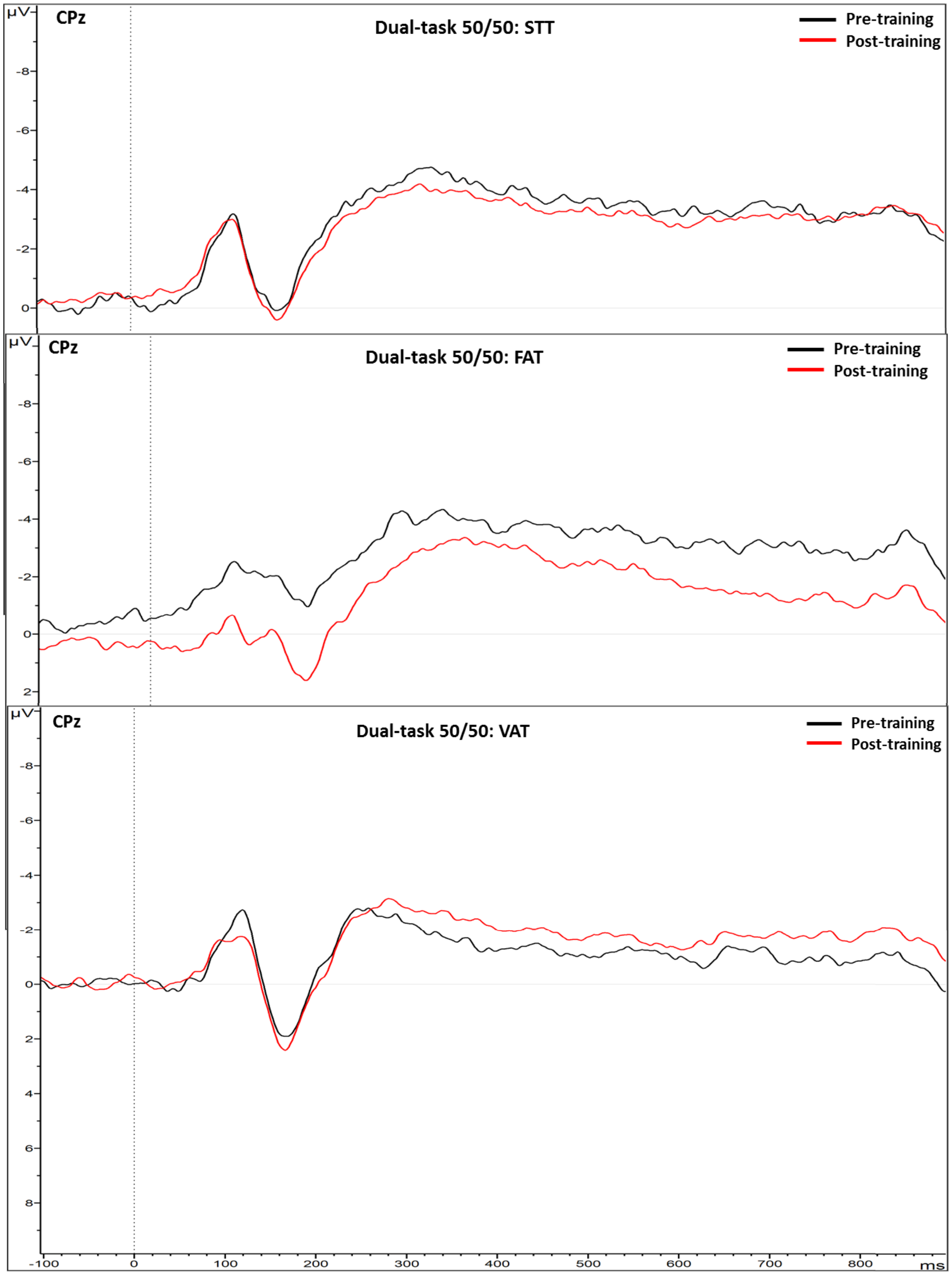


Figure 7. Grand average waveforms at electrode site CPz for participants during the Dual-task 50/50 condition. 0 ms corresponds to the appearance of the equation and the first visual detection bar. The N1-P2 complex is visible from approximately 100 to 200 ms post-stimulus, followed by a sustained negativity from 300 to 750 ms that gradually returned to baseline. Top panel: Single Task Training (STT) group; Middle panel: Fixed Attention Training (FAT); Bottom panel: Variable Attention Training (VAT) group. Black line, pre-training; red line, post-training.

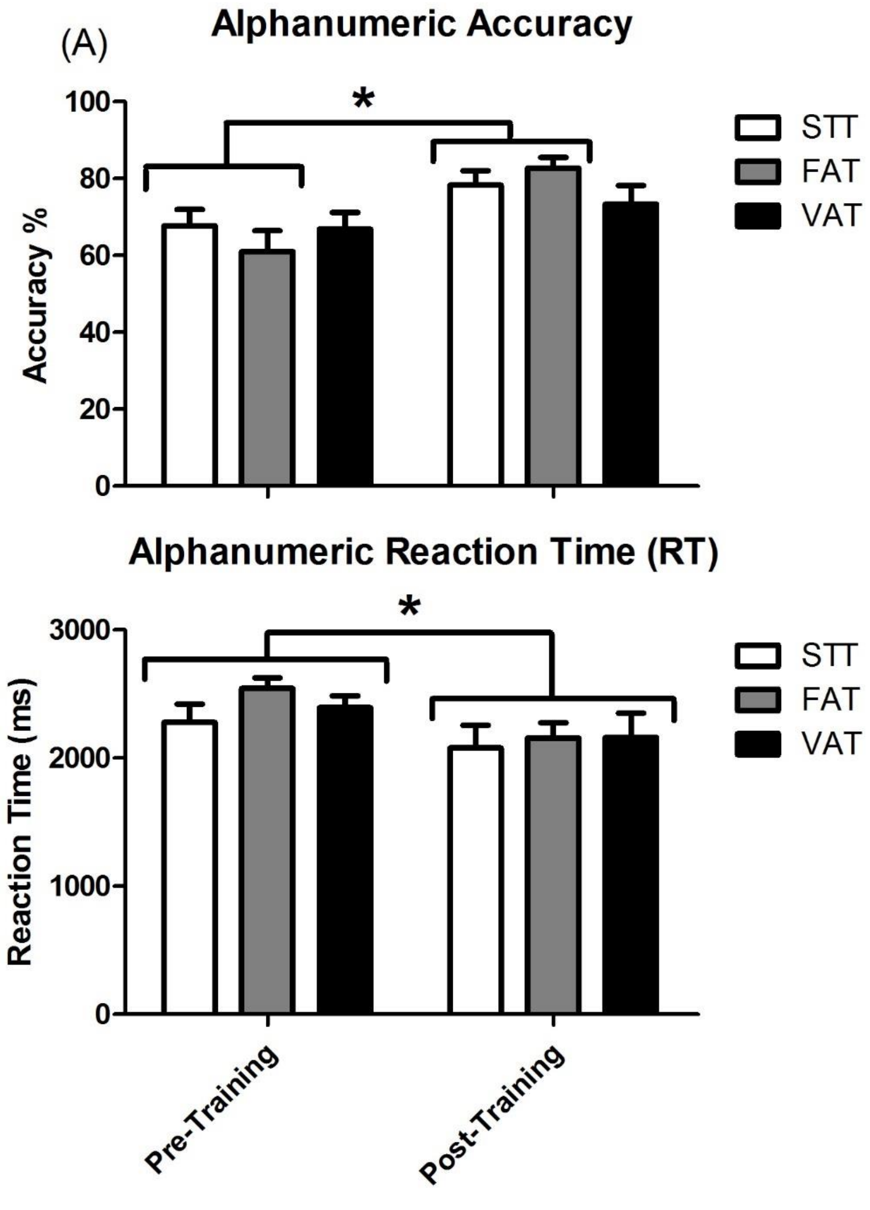


Figure 8. Accuracy (%) and reaction time (ms) for participants performing the alphanumeric equation task during the Dual-task 20/80 condition. STT, Single Task Training; FAT, Fixed Attention Training; VAT, Variable Attention Training. Error bars represent standard error. * $p<0.05$.

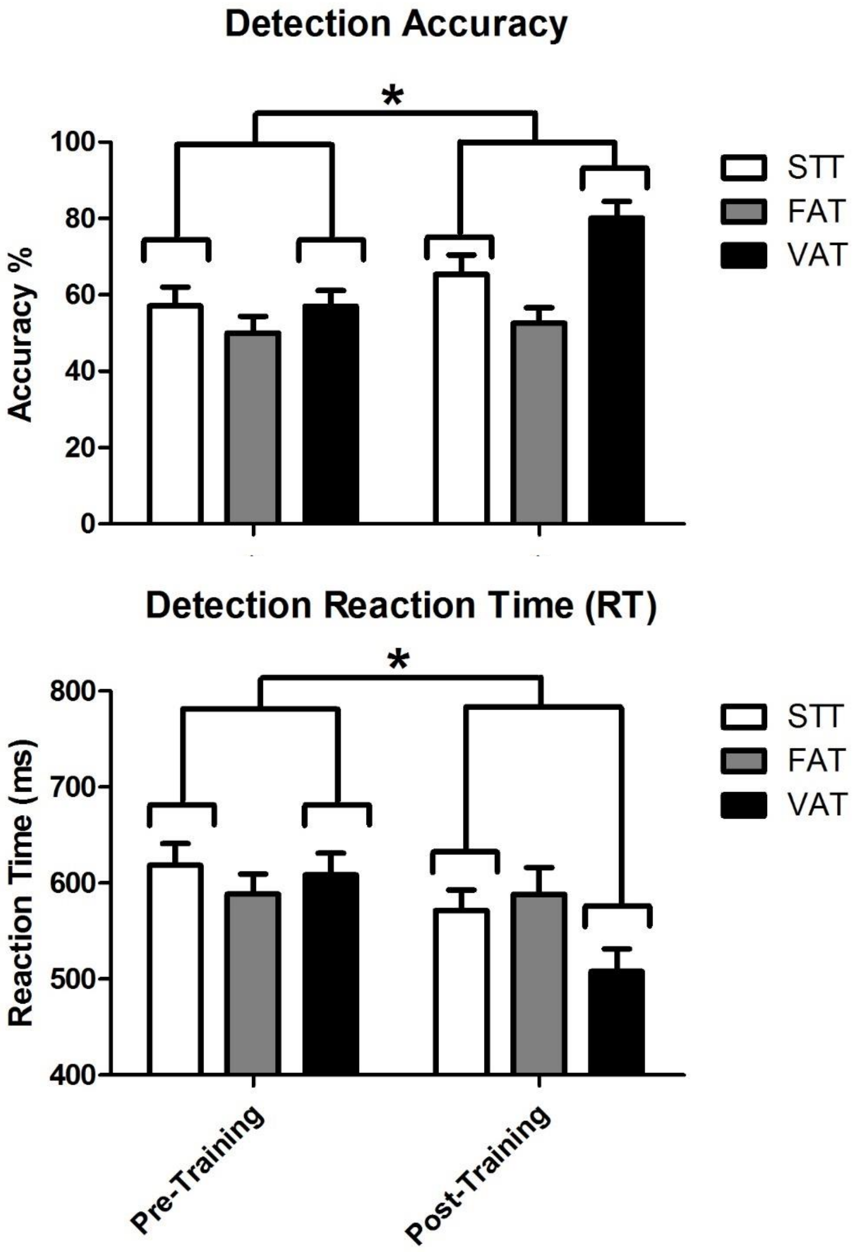


Figure 9. Accuracy (%) and reaction time (ms) for participants performing the visual detection task during the Dual-task 20/80 condition. STT, Single Task Training; FAT, Fixed Attention Training; VAT, Variable Attention Training. Error bars represent standard error. * $p<0.05$.

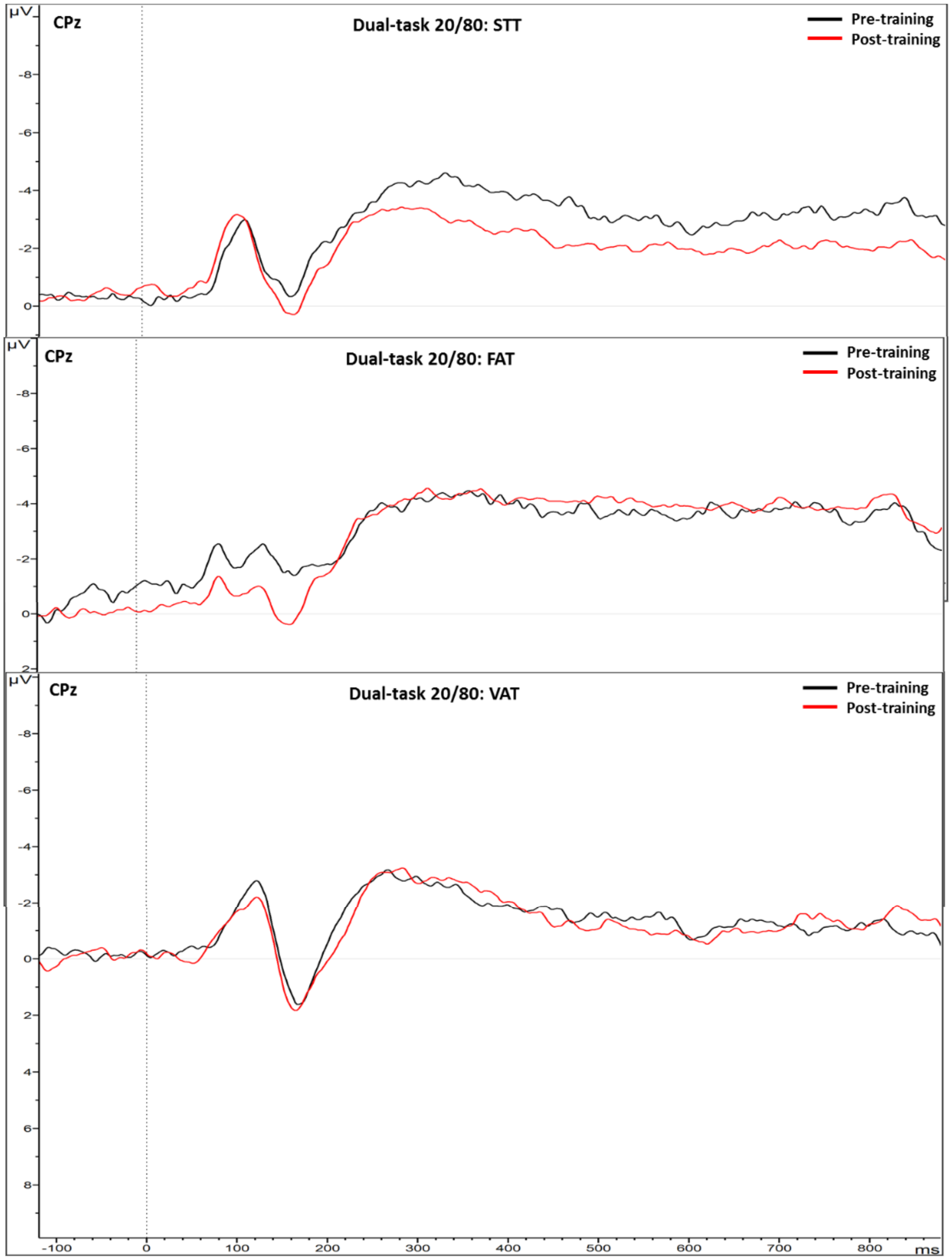


Figure 10. Grand average waveforms at electrode site CPz for participants during the Dual-task 20/80 condition. 0 ms corresponds to the appearance of the equation and the first visual detection bar. The N1-P2 complex is visible from approximately 100 to 200 ms post-stimulus, followed by a sustained negativity from 300 to 750 ms that gradually returned to baseline. Top panel: Single Task Training (STT) group; Middle panel: Fixed Attention Training (FAT); Bottom panel: Variable Attention Training (VAT) group. Black line, pre-training; red line, post-training.

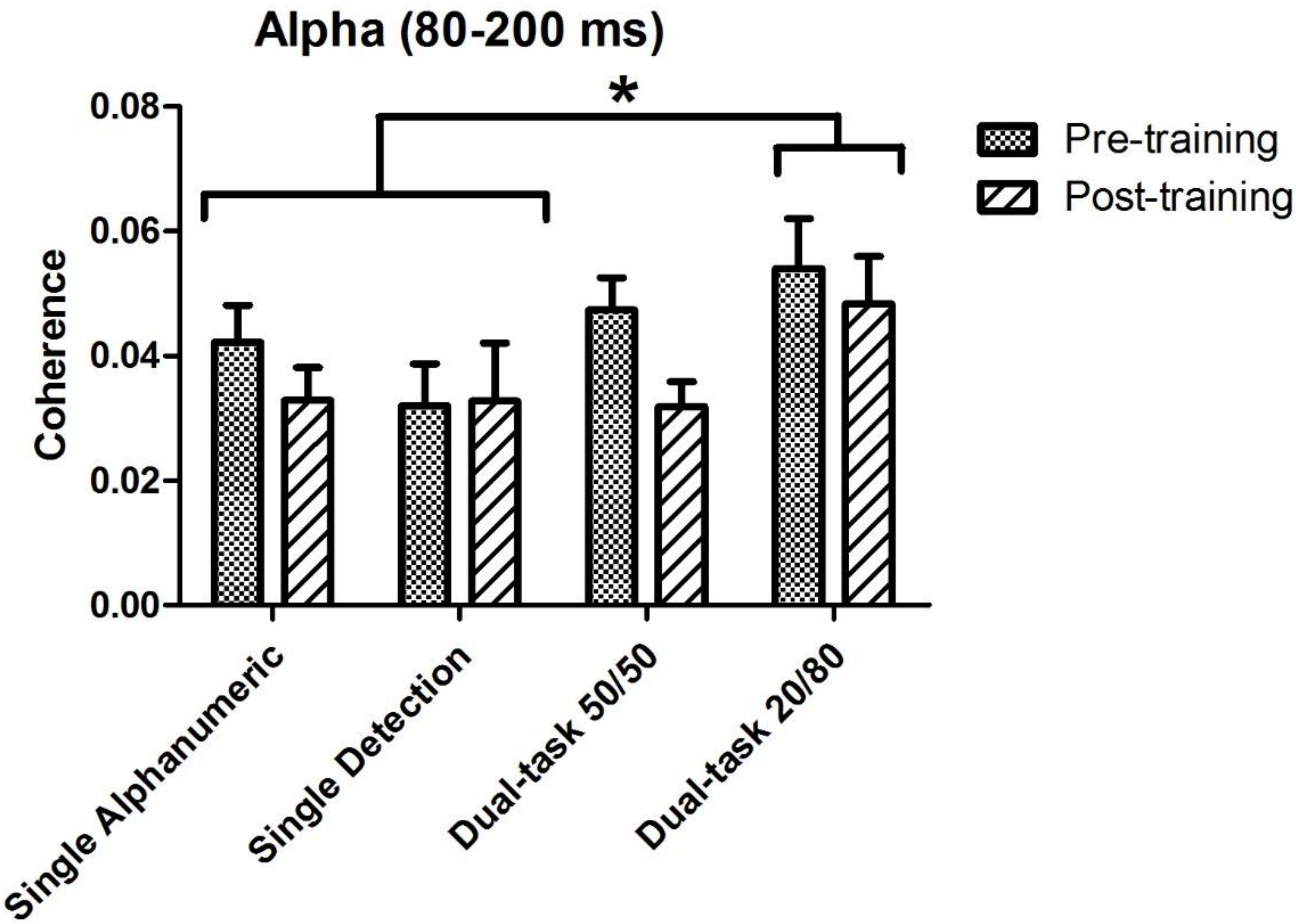


Figure 11. Alpha (7.5-12.5 Hz) band coherence in midline electrode pairs for the different testing conditions. Data are collapsed over groups and electrode pairs. * $p<0.05$ relative to single task conditions.

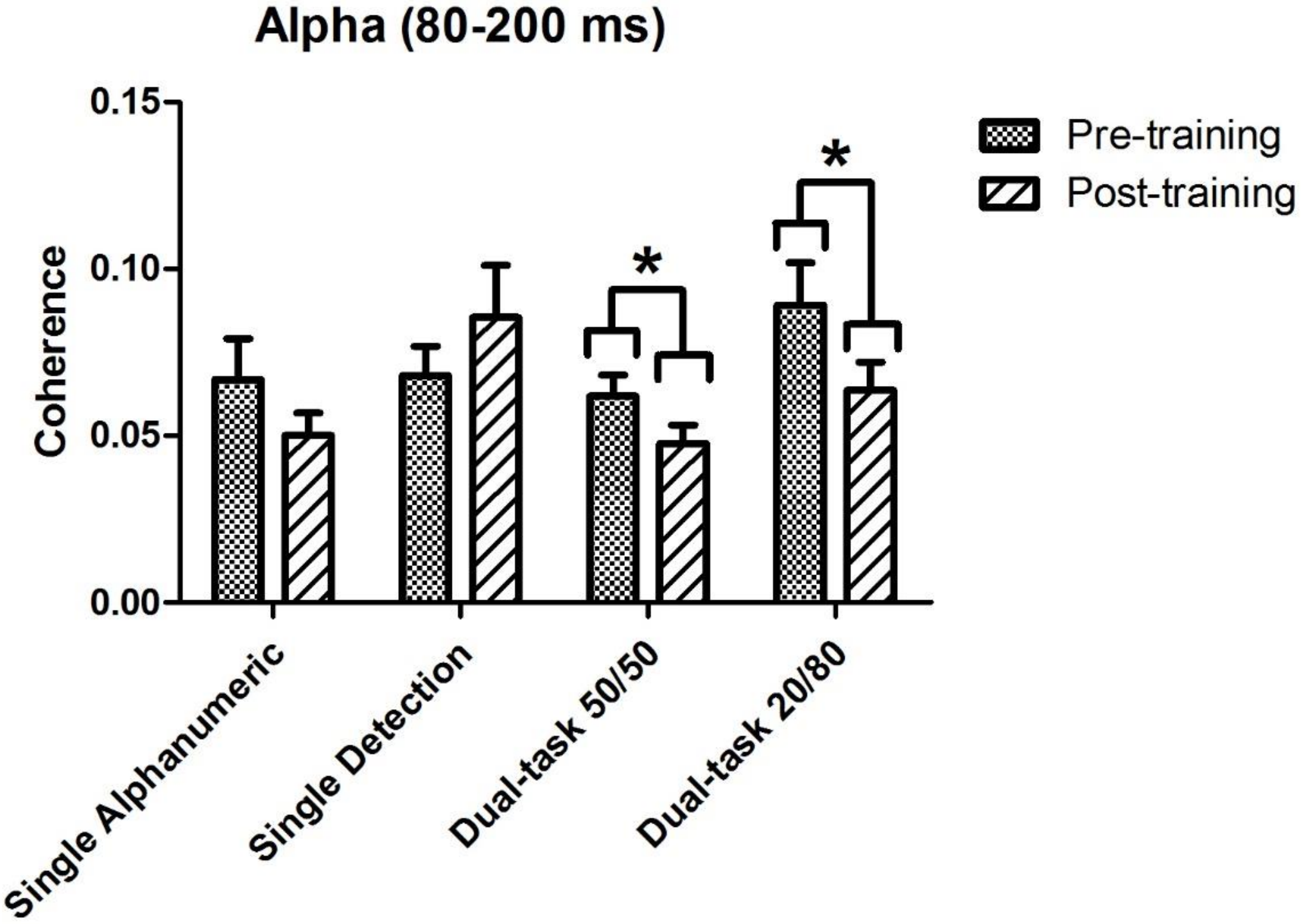


Figure 12. Alpha (7.5-12.5 Hz) band coherence in right brain hemisphere electrode pairs for the different testing conditions. Data are collapsed over groups and electrode pairs. * $p<0.05$ relative to pre-training.

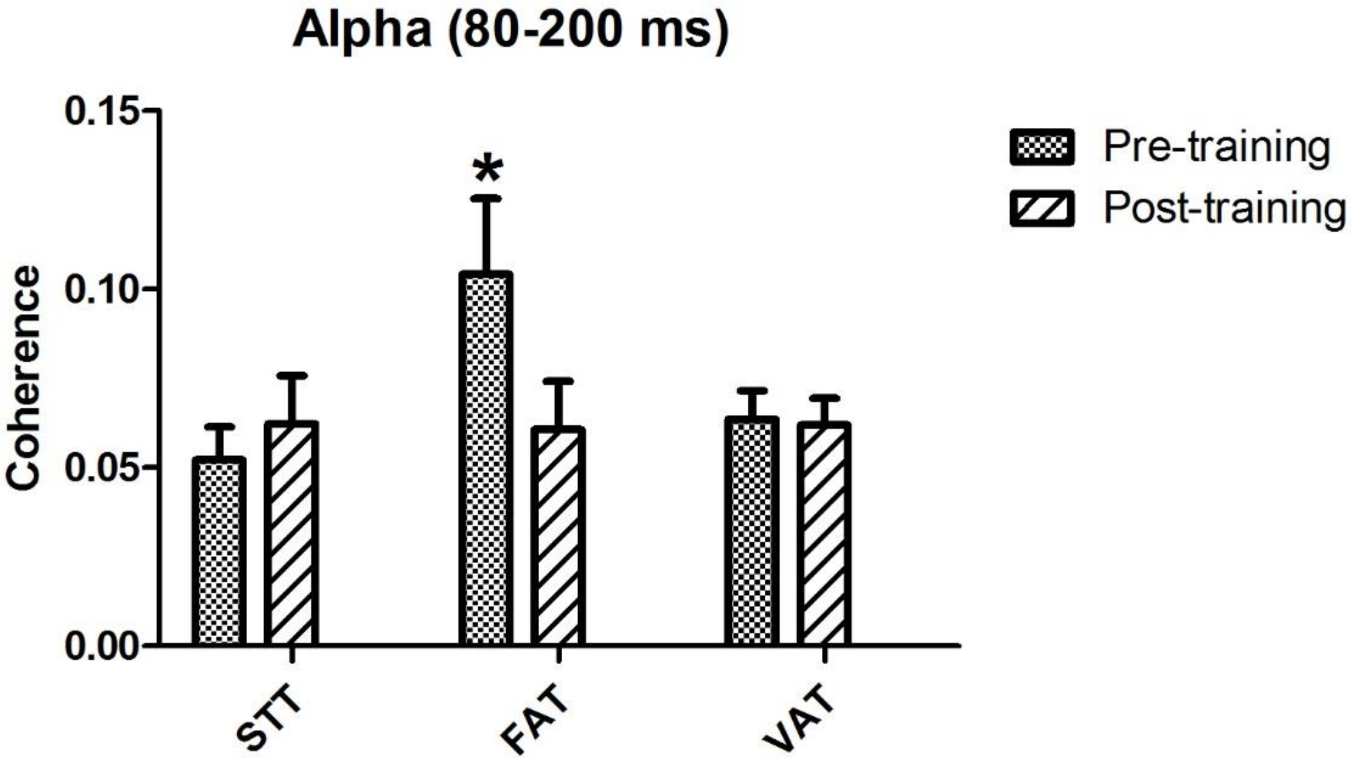


Figure 13. Alpha (7.5-12.5 Hz) band coherence in right brain hemisphere electrode pairs for the different training groups. Data are collapsed over conditions and electrode pairs. * $p<0.05$ relative to FAT post-training and STT, VAT pre-training.

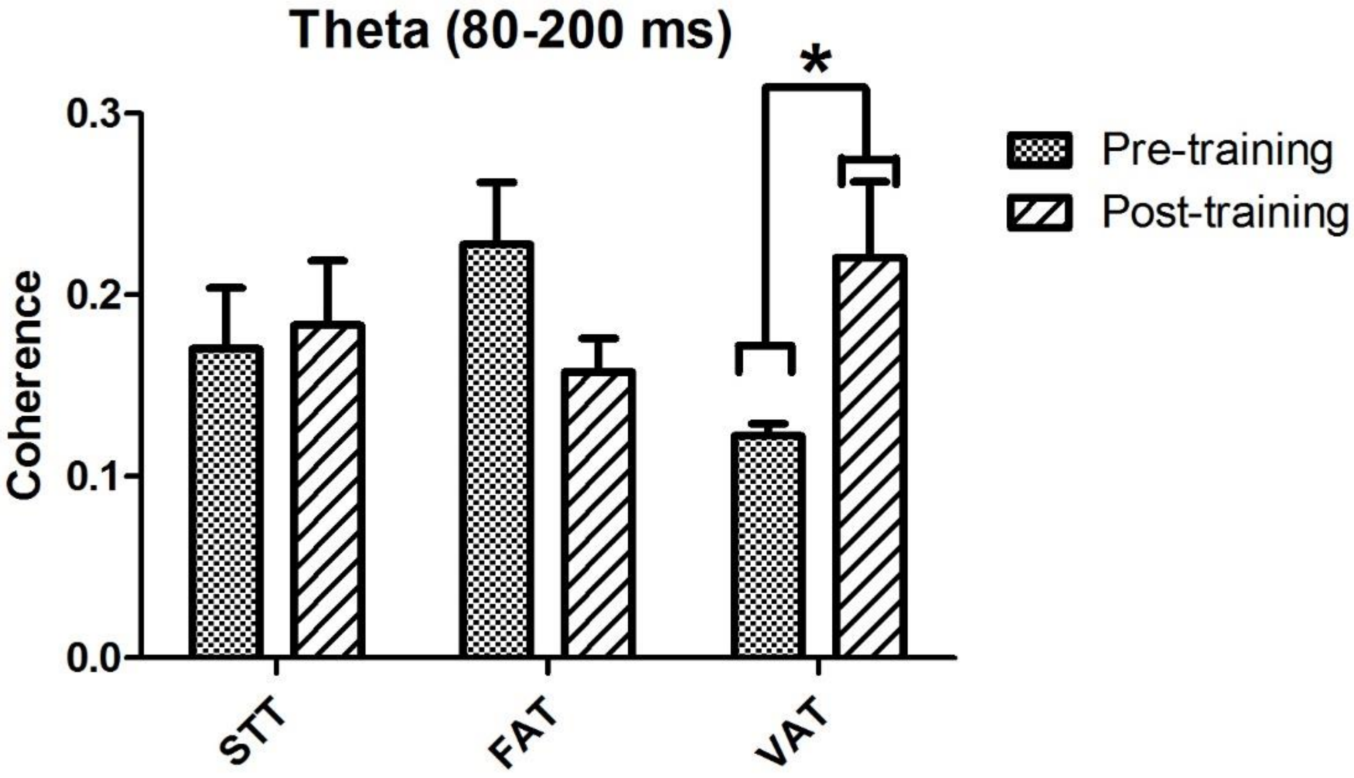


Figure 14. Theta (3.5-7.5 Hz) band coherence in midline electrode pairs for the different training groups. Data are collapsed over conditions and electrode pairs. * $p<0.05$ relative to pre-training.

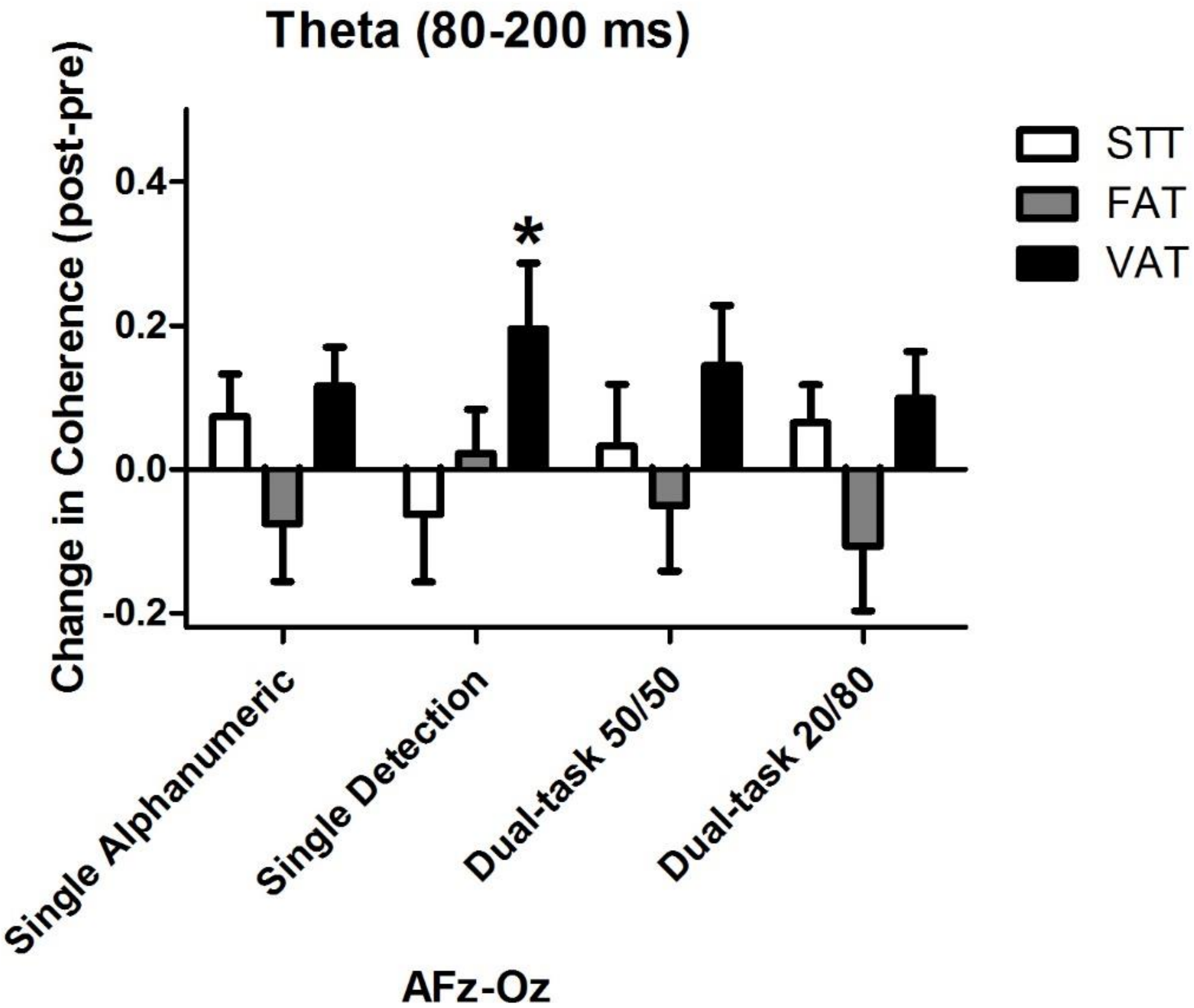


Figure 15. Change in theta (3.5-7.5 Hz) band coherence (post-training – pre-training) in the AFz-Oz midline electrode pair for our three training groups under different testing conditions. Data are collapsed over electrode pairs. * p<0.05 from pre- to post-training.

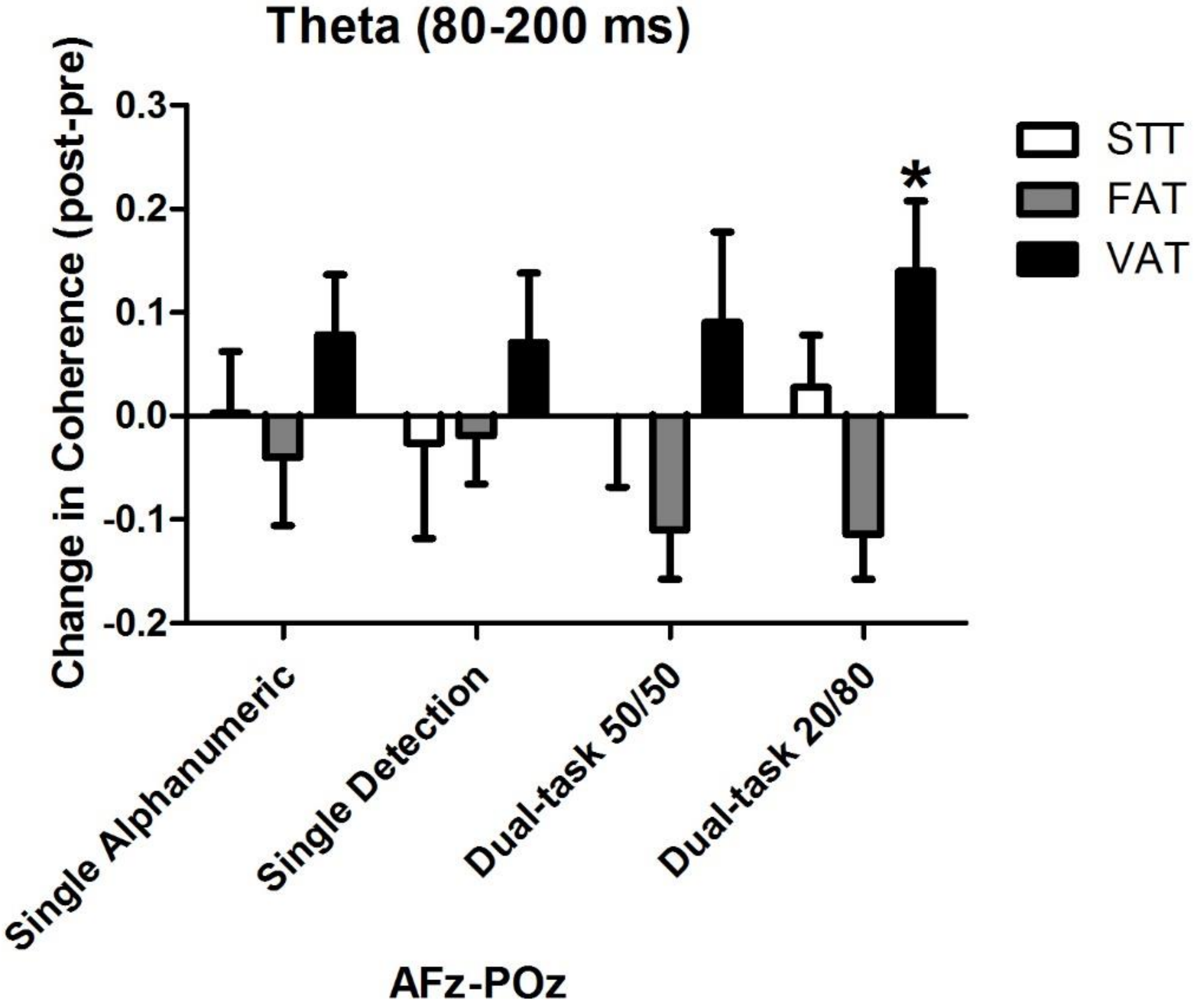


Figure 16. Change in theta (3.5-7.5 Hz) band coherence (post-training – pre-training) in the AFz-POz midline electrode pair for our three training groups under different testing conditions. Data are collapsed over electrode pairs. * $p<0.05$ from pre- to post-training.

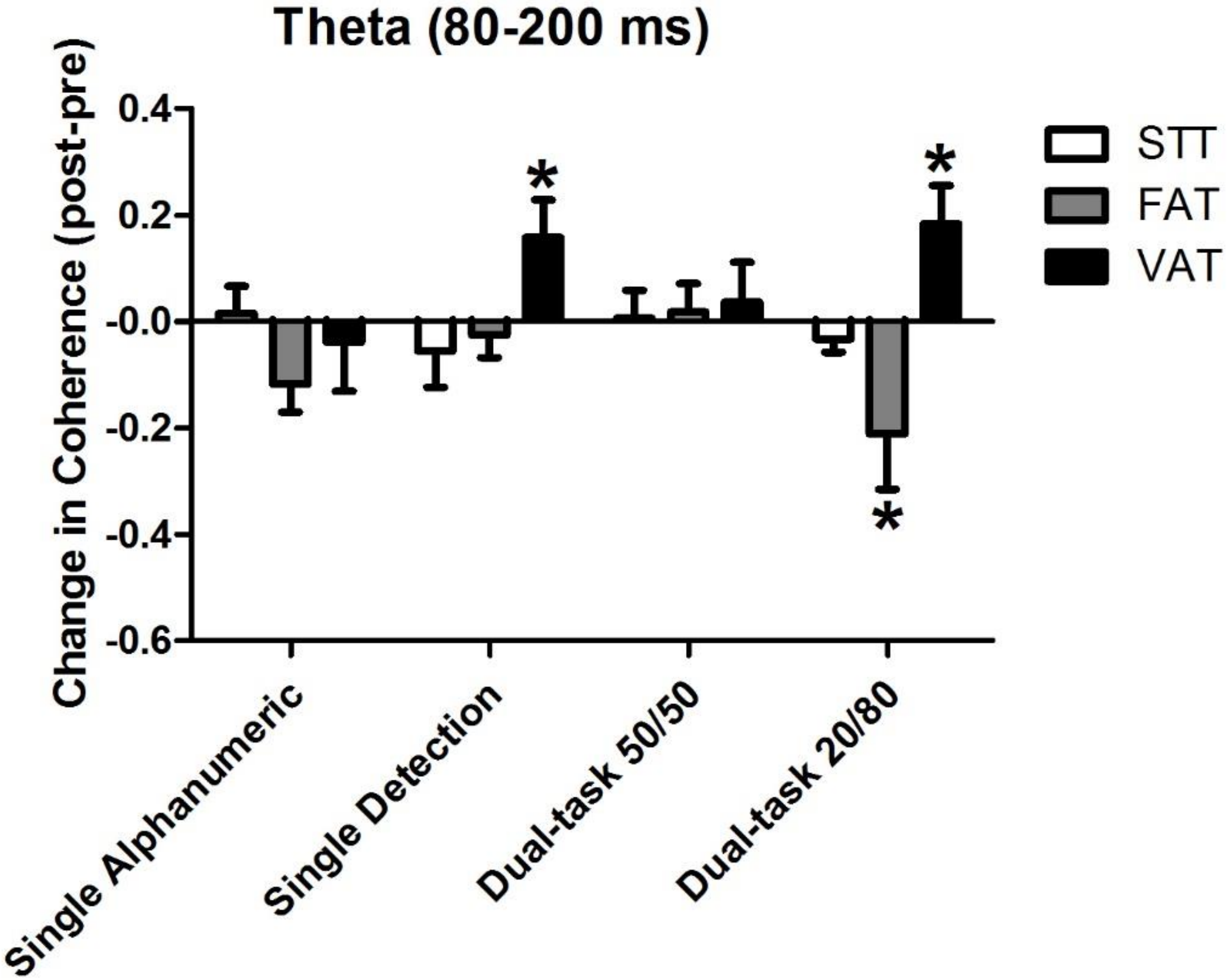


Figure 17. Change in theta (3.5-7.5 Hz) band coherence (post-training – pre-training) in left brain hemisphere electrode pairs for our three training groups under different testing conditions. Data are collapsed over electrode pairs. * $p<0.05$ from pre- to post-training.

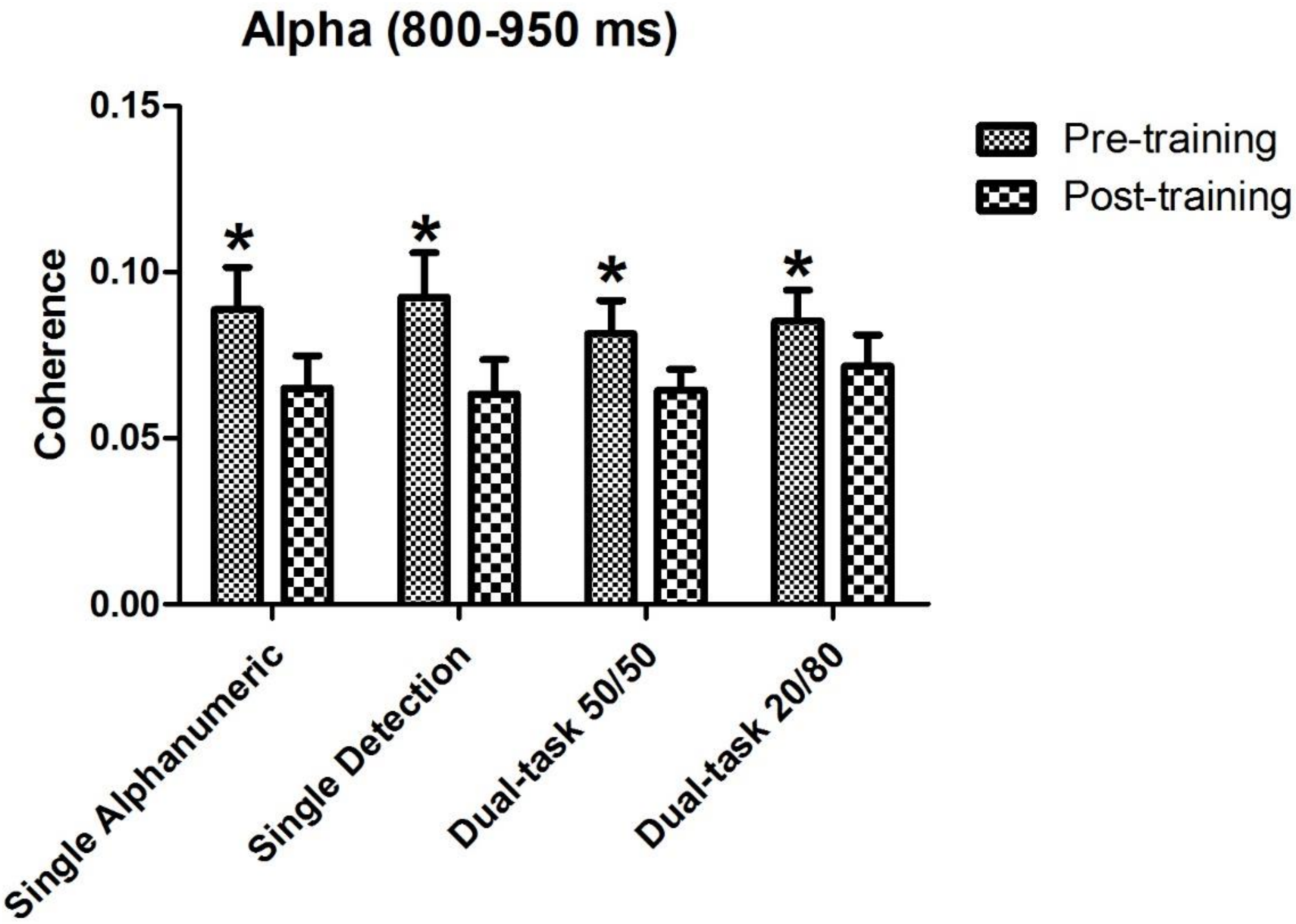


Figure 18. Alpha (7.5-12.5 Hz) band coherence in right brain hemisphere electrode pairs under different testing conditions. Data are collapsed over groups and electrode pairs. * $p<0.05$ relative to post-training.

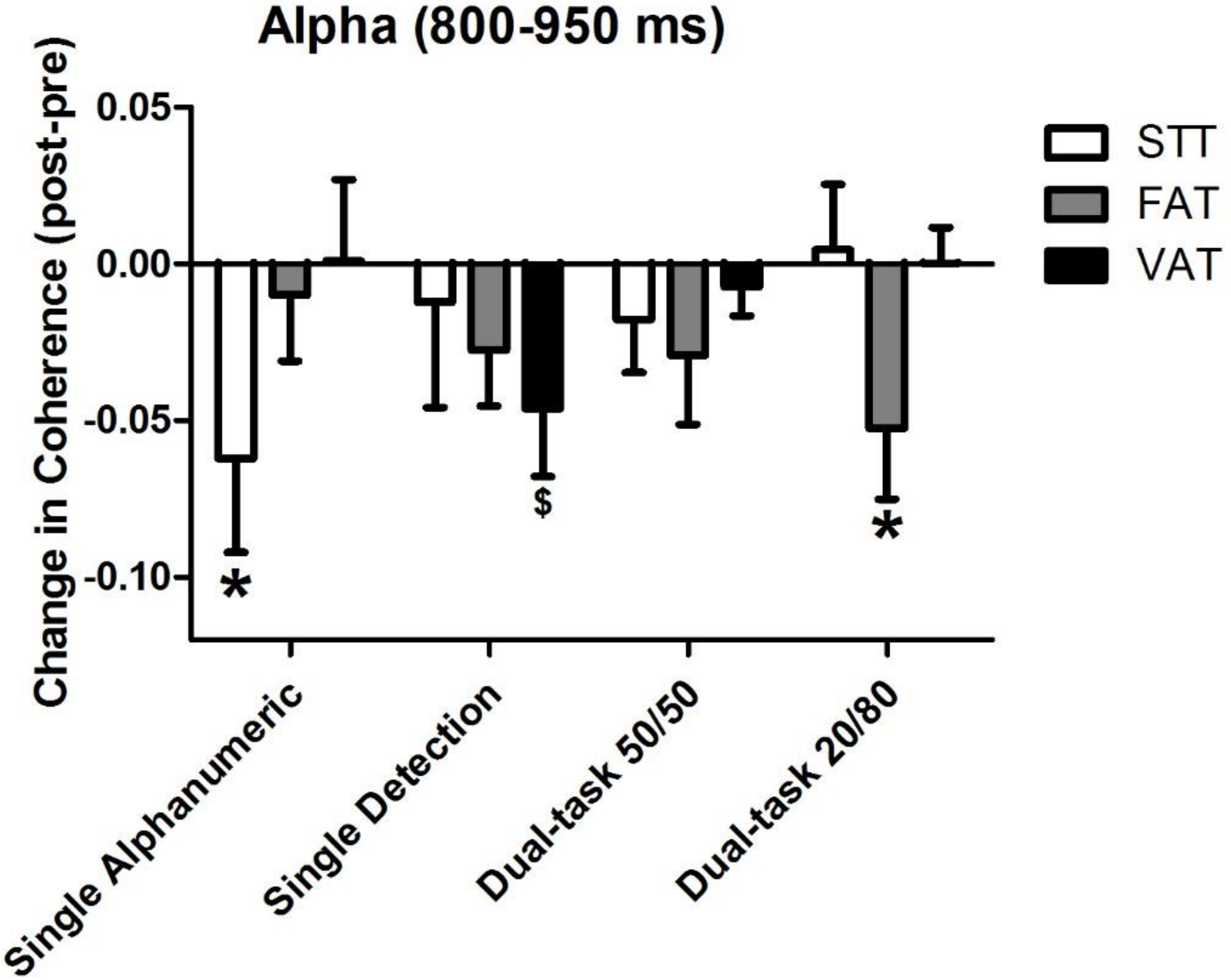


Figure 19. Change in alpha (7.5-12.5 Hz) band coherence (post-training – pre-training) in right brain hemisphere electrode pairs for our three training groups under different testing conditions. Data are collapsed over electrode pairs. * $p<0.05$ from pre- to post-training; $ $p=0.07$ from pre- to post-training.

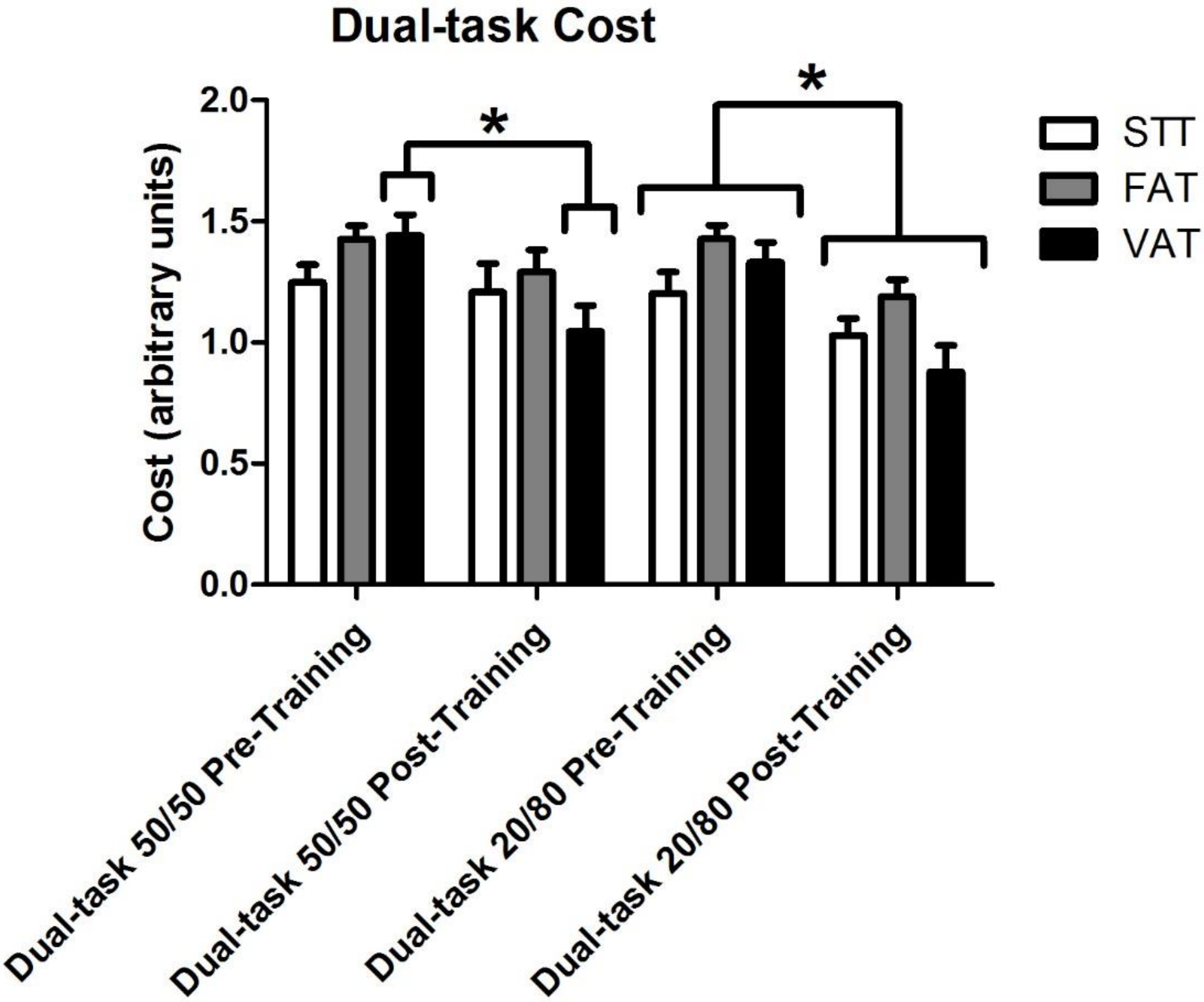
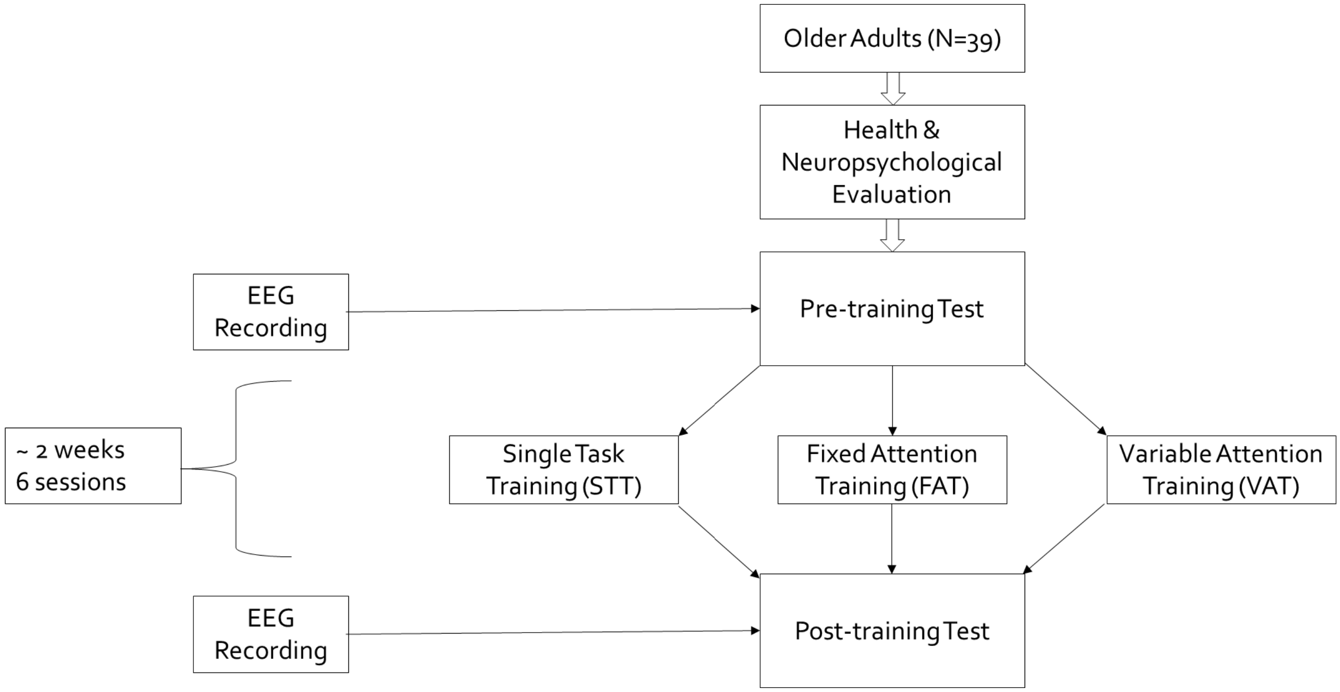
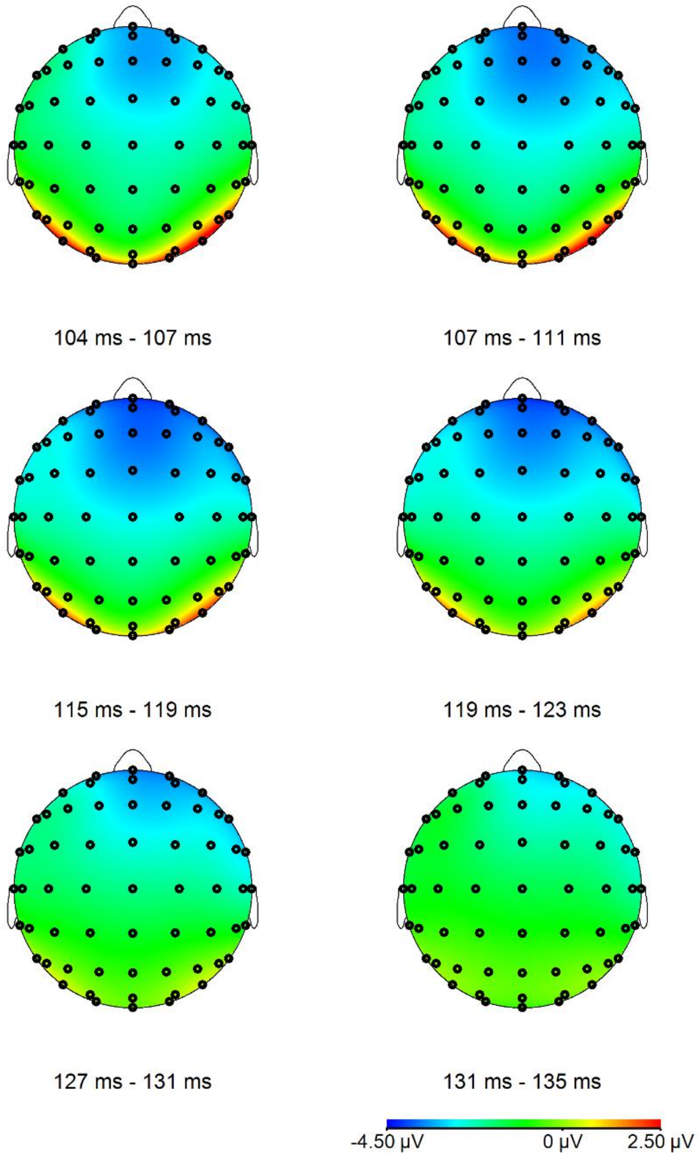


Figure 20. Dual-task cost (see methods section for calculation procedure) for our different training groups in our two dual-task conditions. * $p<0.05$

Appendix A. Schematic of study design



Appendix B. Typical N1 topography observed in the current investigation. Time section (100 – 135 ms) taken from the grand average of participants performing the Individual Equation task prior to training.



104 ms - 107 ms

107 ms - 111 ms

111 ms - 115 ms

115 ms - 119 ms

119 ms - 123 ms

123 ms - 127 ms

127 ms - 131 ms

131 ms - 135 ms

Appendix C. Ethics

R egroupement N euroimagerie / Q uebec
Comite mixte d'ethique de la recherche RNQ

Montreal, le 6 octobre 2006

Madame Sylvie Belleville, Ph.D.
Centre de recherche
Institut universitaire de geriatrie de Montreal
4565, chemin Queen-Mary
Montreal, Quebec H3W 1W5

OBJET : Votre projet de recherche intitule : **«Examen de !'attention dans le vieillissement normal (parties 3 et 4)»** (ref. : CMER-RNQ 06-07-019).

Madame,

Les membres du comite d'ethique vous remercient de leur avoir fait parvenir vos formulaires de consentement modifies selon les modifications qu'ils avaient demandees.

Vous trouverez ci-joint le rapport de l'etablissement valide jusqu 'au 30 septembre 2007 . Un suivi annuel , sous forme de questionnaire , vous sera envoye avant !'expiration de ce delai, et la realisation de cette demarche vous permettra de renouveler le rapport tout au long de votre etude.

Nous vous rappelons que vous devez nous avertir de toute modification au projet de recherche ou au formulaire de consentement .

Par ailleurs, conformement aux directives du Ministere de la Sante et des Services sociaux et tel qu'inscrit au Cadre reglementaire de l'Institut universitaire de geriatrie de Montreal, vous devez constituer un registre des sujets participant a votre projet de recherche. Ce registre comportera les elements suivants : le titre du projet de recherche, le nom et le prenom du sujet , sa date de naissance et ses coordonnees . Il est a noter que ces informations seront tenues confidentielles dans un registre a part, avec un niveau de securite adequat.

Nous vous remercions de votre collaboration et vous souhaitons la meilleure des chances dans ce projet. Veuillez recevoir, Madame, !'expression de nos sentiments les meilleurs.

Johane de Champlain
Presidente
Comite mixte d'ethique de la recherche - RNQ
JdC/gs

Comite mixte d'ethique de la recherche - Regroupement Neuroimagerie/Quebec (CMER-RNQ)
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Regroupement Neuroimagerie /Quebec

Comite mixte d'ethique de la recherche - RNQ

CERTIFICAT D'ETHIQUE

Le comite mixte d'ethique de la recherche du Regroupement Neuroimagerie/Quebec (CMER-RNQ) a examine la demande pour le projet intitule:

«Examen de !'attention dans le vieillissement normal (parties 3 et 4)»
(ref. : CMER-RNQ 06-07-019).

presente par : **Madame Sylvie Belleville, Ph.D.**

et juge la recherche acceptable au point de vue ethique.

J de Champlain

Johane de Champlain, presidente

Date : 6 octobre 2006

Ce certificat d'ethique est valide jusqu 'au : 30 septembre 2007

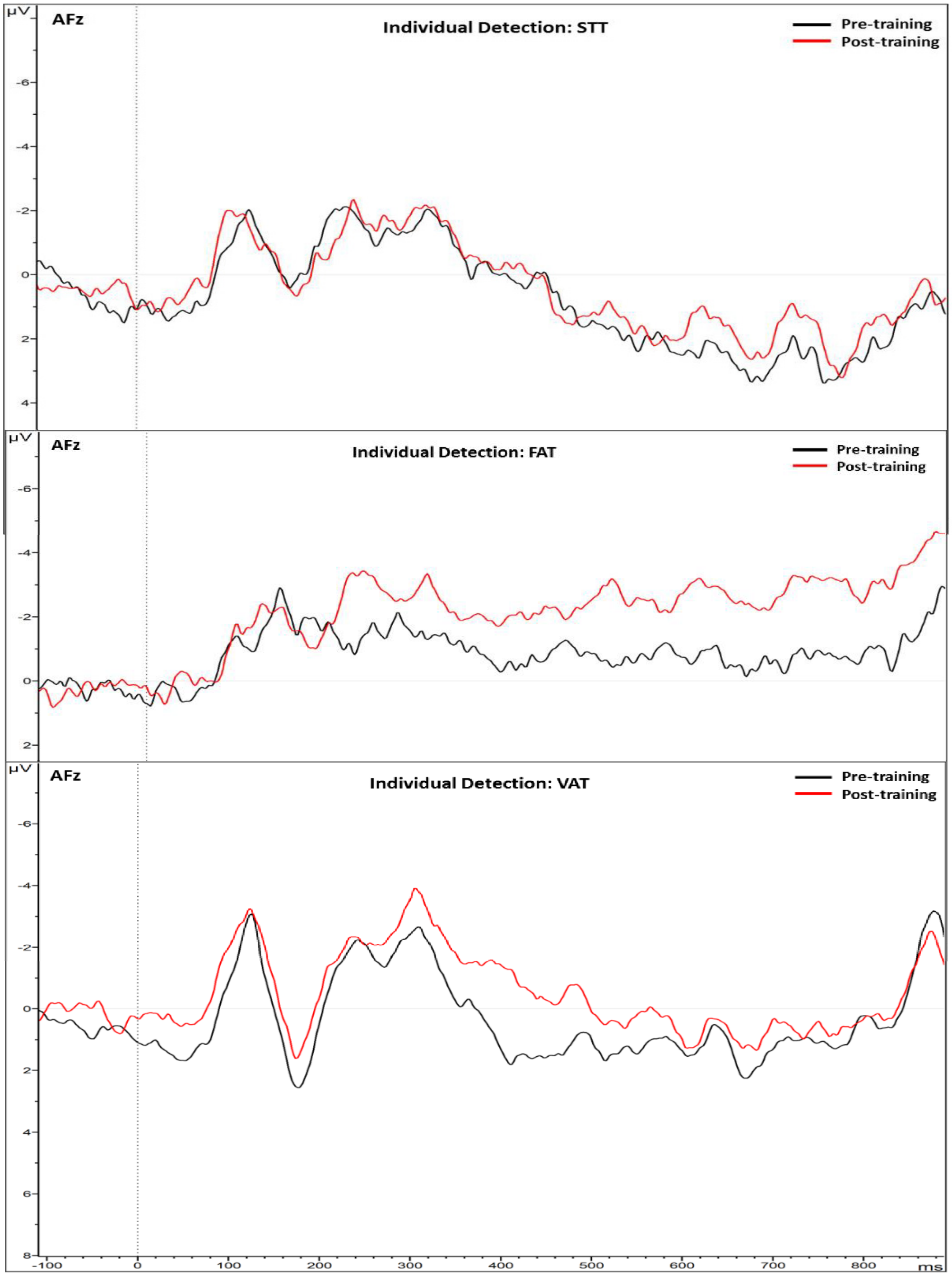

Figure 4: Grand average waveforms at electrode site AFz for participants performing the individual visual detection task. The N1-P2 complex is visible from approximately 100 to 200 ms post-stimulus, followed by a sustained negativity from 300 to 750 ms that gradually returned to baseline. Top panel: Single Task Training (STT) group; Middle panel: Fixed Attention Training (FAT); Bottom panel: Variable Attention Training (VAT) group. Black line, pre-training; red line, post-training.

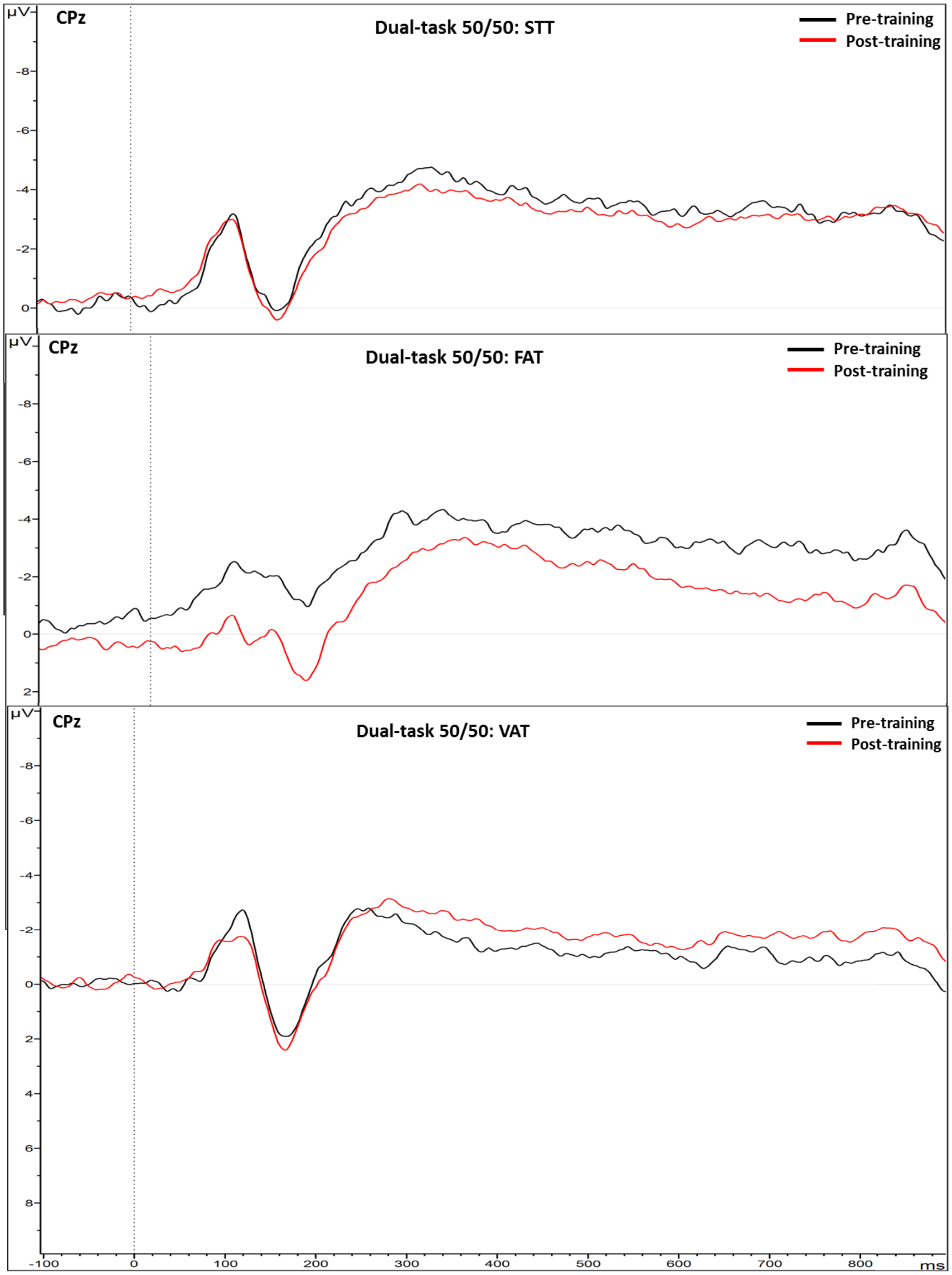

Figure 7. Grand average waveforms at electrode site CPz for participants during the Dual-task 50/50 condition. 0 ms corresponds to the appearance of the equation and the first visual detection bar. The N1-P2 complex is visible from approximately 100 to 200 ms post-stimulus, followed by a sustained negativity from 300 to 750 ms that gradually returned to baseline. Top panel: Single Task Training (STT) group; Middle panel: Fixed Attention Training (FAT); Bottom panel: Variable Attention Training (VAT) group. Black line, pre-training; red line, post-training.

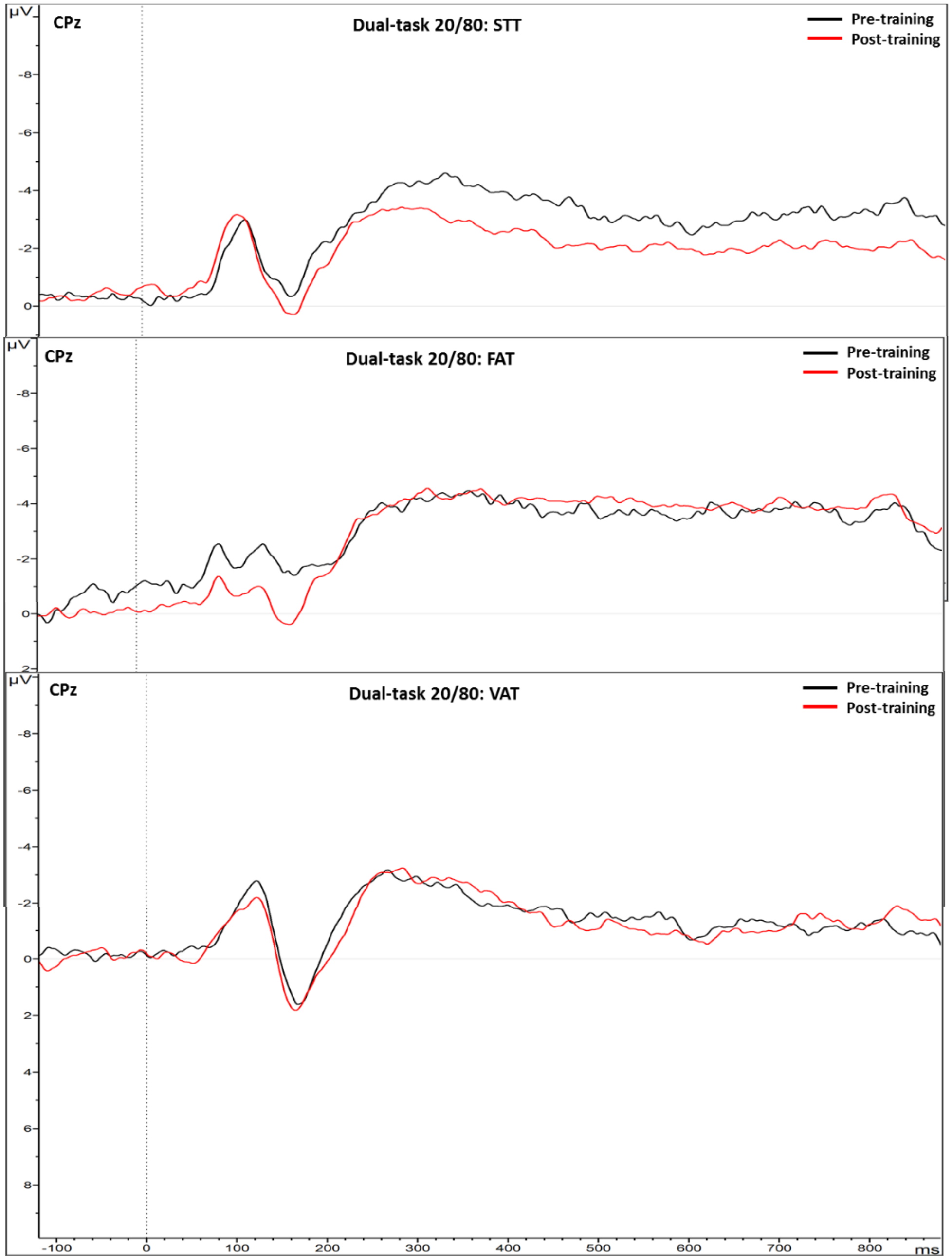

Figure 10. Grand average waveforms at electrode site CPz for participants during the Dual-task 20/80 condition. 0 ms corresponds to the appearance of the equation and the first visual detection bar. The N1-P2 complex is visible from approximately 100 to 200 ms post-stimulus, followed by a sustained negativity from 300 to 750 ms that gradually returned to baseline. Top panel: Single Task Training (STT) group; Middle panel: Fixed Attention Training (FAT); Bottom panel: Variable Attention Training (VAT) group. Black line, pre-training; red line, post-training.

Appendix A. Schematic of study design