The impact of attentional training on event-related potentials in older adults

Benjamin Rich Zendel a, b, *, Chloé de Boysson b, Samira Mellah b, Jean-François Démonet c, Sylvie Belleville b, d

a Division of Community Health and Humanities, Faculty of Medicine, Memorial University of Newfoundland, Health Sciences Centre, St. John’s, Newfoundland and Labrador, Canada
b Centre de Recherche, Institut Universitaire de Gériatrie de Montréal (CRIUGM), Montréal, Québec, Canada
c Département de Psychologie, Université de Montréal, Pavillon Marie-Victorin, Montréal, Québec, Canada
d Département Neurosciences Clinique, Centre Leenaards de la Mémoire, Centre Hospitalier Universitaire Vaudois (CHUV), Lausanne, Switzerland

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A B S T R A C T
Attentional control declines in older adults and is paralleled by changes in event-related brain potentials (ERPs). The N200 is associated with attentional control, thus training-related improvements in attentional control should be paralleled by enhancements to the N200. Older participants were randomly assigned to 1 of 3 groups, which focused on training different levels of attentional control: (1) single-task training (single), where participants trained on 2 tasks in isolation; (2) fixed divided attention training (fixed), where participants trained on 2 tasks simultaneously; and (3) variable divided attention training (variable), where participants trained on 2 tasks simultaneously but were instructed to alternatively prioritize each of the 2 tasks. After training, the amplitude of the N200 wave increased in dual-task conditions for the variable group, and this enhancement was correlated with improved dual-task performance. Participants in the variable group also had the greatest improvement in the ability to modulate their allocation of attention in accordance with task instructions to the less salient and less complex of the 2 tasks. Training older adults to modulate their division of attention between tasks improves neural functions associated with attentional control of the trained tasks.

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1. Introduction

The ability to orient and modulate attention to select the most efficient strategy to complete a cognitive task is known as attentional control (Baddeley and Hitch, 1974; Norman and Shallice, 1986) or executive attention (Posner and Rothbart, 2007). It is now well-established that the ability to control attention declines with age (Verhaeghen and Cerella, 2002), and this decline leads to increased difficulty performing 2 tasks simultaneously (Verhaeghen et al., 2003). This age-related decline can negatively impact many day-to-day activities that require attentional control, such as driving a car, crossing a busy intersection, or completing a series of errands. Importantly, research suggests that this progressive decrease in attentional control can be reduced by intervention, as the training of attentional control has been shown to improve dual-task performance in older adults (Bier et al., 2014; Kramer et al., 1995). However, little is known regarding the brain mechanisms underlying intervention-related cognitive changes. Neurophysiologically, age-related decline in attentional control is often paralleled by changes to event-related potentials (ERPs) derived from the continuous electroencephalogram (EEG; Kok, 2000; Kray et al., 2005). Accordingly, the purpose of the present study was to investigate how an intervention focused on training attentional control impacts ERPs related to dual-task performance in a group of older adults.

1.1. Dual-task training in older adults

Emerging evidence suggests that healthy older adults can improve their ability perform 2 tasks simultaneously with training. The critical factor for this improvement is likely an improved ability to flexibly control attention. Evidence for this comes from Kramer et al. (1995), who compared a fixed divided attention training protocol to a variable divided attention training protocol. In the fixed protocol, participants practiced dividing their attention equally between a visual monitoring task and an alphabet-arithmetic task. This condition entailed dividing attention without...
modulating attention between the tasks. In the variable protocol, participants varied their attentional allocation between the 2 tasks, alternatively favoring one over the other, thus practicing attentional control. Only participants in the variable training protocol improved dual-task performance, whereas performance of each of the tasks in isolation was improved in both groups (Kramer et al., 1995). This pattern of results suggests that attentional flexibility may be an important factor for attentional control (Kramer et al., 1995). In a follow-up study, Kramer et al. (1999) found a similar pattern of results using different tasks. Interestingly, in this follow-up, the group trained using the variable training protocol also exhibited greater transfer to novel tasks requiring attentional control (Kramer et al., 1999). Further support for the benefit of variable training protocols comes from 2 recent studies from our laboratory. We found that variable training protocols improved the ability to modulate attentional demands during dual-task performance, whereas both fixed-training protocols and single-task training did not (Belleville et al., 2014; Bier et al., 2014).

Other studies have also found benefits to attentional control from fixed-training protocols. Bihler et al. (2005) trained participants over 5 sessions using a bimodal integration task (visual and auditory). In this study, both fixed and variable training protocols proved beneficial to older adults, but no difference between the fixed and variable training protocols was reported. The lack of difference may have been because the variable training protocol required participants to prioritize the timing of their responses in the dual-task conditions (i.e., perform 1 task before the other). In this study, the variable-priority protocol trained prioritization, not attentional control. It is therefore likely that to improve attentional control, participants should not be instructed to temporally prioritize 1 task over the other. In another study, Anguera et al. (2013) used a video game–based driving task and asked older participants to control a virtual car while simultaneously detecting a visual signal. Participants were then randomly assigned to 1 of 3 training groups. One group practiced the dual-task version of the game (i.e., driving and detecting a visual signal), a second group practiced the driving task and the visual detection task separately for the same time-period, and the third group served as a no-contact control. After training, those in the dual-task group had the greatest reduction in dual-task cost, and at a 6-month follow-up, the dual-task group retained this benefit. At the surface, these results suggest a benefit for fixed dual-task training; however, driving is a complex and dynamic task that requires near constant attention. Moreover, the amount of attention is constantly modulated depending on the situation. For example, navigating a turn would require more attention than driving in a straight line. Although the training in this study was not explicitly variable, it is likely that participants were automatically modulating their allocation of attention throughout the training sessions. If this interpretation is correct, then this finding suggests that variable-priority training can be induced by using training tasks that implicitly modulate attention. Based on all the research, it is likely that explicitly or implicitly training how to modulate attention will improve attentional control in older adults and that there is the potential to use variable priority attentional training to improve attentional control in real-world situations.

1.2. Neurophysiological effects of attentional training in older adults

In addition to behavioral studies, there have also been neurophysiological investigations of variable attentional training protocols in older adults. In the driving simulator study reported above, Anguera et al. (2013) also reported a posttraining increase in frontal theta-band power and frontal-parietal theta band coherence that was largest for the dual-task group. This pattern of results is suggestive of an enhancement to the frontal attentional control network (Anguera et al., 2013). In support of this finding, Belleville et al. (2014) found that variable attentional training protocols enhanced neural activity in the right frontal gyrus compared with fixed-priority and single-task training protocols. Given that attentional control was improved in the variable-priority training group in both these studies, it is likely that learning to prioritize certain tasks alters frontal brain regions and their functional connectivity related to attentional control. Other studies have investigated training attentional control but have not specifically utilized variable training protocols. Erickson et al. (2007) found that older adults who received divided attention training had increased hemispheric asymmetry for activity in the ventral and dorsal prefrontal cortices, and altered functioning in the anterior cingulate and prefrontal cortex. Decreased hemispheric asymmetry is thought to be related to neurological aging (Cabeza, 2002), and the anterior cingulate and prefrontal cortex are associated with the attentional network (Posner et al., 2007). Accordingly, it is likely that interventions that focus on training the ability to divide attention can reduce the impact of aging on the attentional network.

The engagement of attentional control during dual-task performance takes time, and the impact of training is unlikely to be temporally uniform during performance of the tasks. Electrophysiological brain recordings can provide insight into the time course of training-related brain plasticity. Previous work suggests that the N200 ERP is related to performance on tasks that involve attentional control; however, these studies have been inconsistent in terms of which mechanism of attentional control is related to the N200. For example, Van Gaal et al. (2011) reported that the N200 response was related to the initiation of inhibitory control during a stroop task. On the other hand, Donkers and Bokxel (2004) found that an N200 could be evoked when response inhibition was not required by the task. In this study, the N200 was impacted by a task that required modulation of the force of a manual response, suggesting that the N200 is related to conflict monitoring. Both interpretations of the N200 support the idea that it is an index of attentional control; differences between the tasks demonstrate that the N200 may represent a stage of processing related to attentional control and not a specific subcomponent of it. For the present study, the N200 is particularly interesting because it is sensitive to attentional training in both children and adults (Eldar and Bar-Haim, 2010; Rueda et al., 2005; Schapkin et al., 2007). Moreover, the posterior portion of the N200 (i.e., N2pc) related to visuospatial attentional orienting is reduced and delayed in older adults (Lorenzo-Lopez et al., 2008). Using a visuospatial attentional orienting task, O’Brien et al. (2013) found and enhanced N2pc in older adults after training on a speeded visual processing task, compared to a group of controls. Although the N2pc is not directly related to dual-task performance, it is related to attentional control in terms of visuospatial orienting. Critically, this suggests that ERPs related to attentional control can be modified in older adults. The influence of attentional training on the N200 while performing dual-tasks requiring attentional control remains unknown. Furthermore, it is possible that attentional training may have an impact on earlier ERPs that reflect basic visual processing, such as the P1 or N1. This early enhancement in visual processing could have a cascading effect on subsequent neurocognitive task demands.

1.3. Rationale

To determine the impact of attentional training on the N200, we randomly assigned a group of healthy older adults into 3 groups. One group practiced an alphanumeric equation verification task and a visual detection task in isolation (Single); the second group practiced...
both tasks simultaneously (Fixed); the third group practiced both tasks simultaneously but varied how they prioritized each task (Variable). Before and after training, participants were tested on their ability to accurately modulate attention while performing both tasks. Like previous studies (e.g., Belleville et al., 2014; Bier et al., 2014; Kramer et al., 1995), we expect the performance of the Variable group to improve the most and that this improvement will parallel the specific task demands related to how participants are asked to modulate their attention. That is, performance will improve on a task when the attentional priority is placed on that task. Furthermore, we expect an enhanced N200 in the Variable group across all conditions, reflecting the neuroplacticy related to training attentional control. If the N200 is a neurophysiological mechanism related to attentional control, then the post-training enhancement of the N200 should be related to improved task performance when attentional allocation needs to be modulated between the 2 tasks.

2. Methodology

2.1. Participants

Thirty-nine older adults from 60 to 85 years of age were recruited through postings in magazines, in cultural centers, and through a laboratory list of participants. Participants were screened through a telephone interview, and exclusion criteria included dementia, serious health problems, chronic psychiatric disorders, cerebrovascular disease, head trauma, cerebral infection, metabolic dysfunction, thyroid dysfunction, epilepsy psychosis, schizophrenia, drug or alcohol abuse, vision deficits, and reduced hand mobility, in addition to medication that could impact cognitive and cerebral functioning. To ensure participants were free of cognitive impairment and depression, they completed the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) and the Geriatric Depression Scale (GDS; Yesavage et al., 1983) before being recruited into the study. No participants were recruited into the study that scored outside the normal range on these 2 tests (i.e., <26 for the MoCA and >5 for the GDS). Three participants (1 from each group) were excluded from the analysis due to technical difficulties with their EEG data. The participants in this study were the same from Belleville et al., 2014 and Bier et al., 2014; however, all task-related data (ERP and behavioral) are novel and have not been reported elsewhere.

2.2. Study design

Participants were randomly assigned to 1 of 3 training conditions: variable-priority divided attention training (variable), fixed-priority divided attention training (fixed), and single-task training (single). Random assignment to each of the 3 training groups was stratified by education level and age to equate the groups on those factors and was carried out by a research technician independent of the study. Training was provided in six 1-hour sessions spread over 2 weeks. Pretraining clinical assessments were administered 2–3 weeks before training onset, and the pretraining experimental tasks were administered 1–2 weeks before training onset. One to two weeks following the cessation of training, participants returned for a post-training assessment. Two versions of each task were available and the order (pre/post-test) was counterbalanced across participants.

2.3. Experimental tasks

Two tasks were used to assess the ability to divide attention. The first was an alphanumeric equation task and the second was a visual detection task (see in the following section). These 2 tasks were chosen because of their differing level of complexity, with the alphanumeric equation task being more difficult and more salient than the visual detection task. Controlling attention between 2 tasks that differ in complexity is more reflective of real-world situations where individuals must control their attention between multiple tasks that differ in complexity and salience. In addition, these 2 tasks were chosen to minimize response selection competition so that the 2 tasks could be easily performed by the participants. The tasks were administered separately in focused attention conditions and concurrently in 3 divided attention conditions (i.e., different levels of attention were allocated to each task while performed simultaneously). All stimuli were presented on a 17" screen using E-Prime software (ver. 1.1). Each trial was 3.5 second in duration, followed by a series of five stars for fixation presented for 1.5 second at the center of the screen. Responses were recorded by a Cedrus (RB-830) response pad, and EEG was monitored throughout. See Fig. 1 for a visual representation of the tasks.

2.3.1. Alphanumeric equation task

Participants were required to verify the accuracy of a set of alphanumeric equations presented in the centre of the screen in white text. Equations were constructed by combining a letter (A–M) and a number (1 or 2) in the form of an addition or a subtraction (e.g., B + 2 = D; D − 1 = C, …). To verify the equation, the participant had to use the first letter as a starting point, the + or − sign to determine the direction of the equation, and the digit to indicate the number of alphabetic “steps” to reach the correct letter. For example, in the equation B + 2 = D, the starting point is B and the letter D is 2 positions forward in the alphabet, thus this equation correct. In each condition that included the Alphanumeric Verification task (see below), 96 alphanumerical equations were presented, and half were correct. There were 2 restrictions: the answer had to be part of the first half of the alphabet (A–M) and equations containing the letter I were excluded to avoid confusion with the digit 1. In each block, the number of equations that used addition or subtraction and had a digit of 1 or 2 was equivalent.

2.3.2. Visual detection task

Participants were presented with a series of red and white bars presented just below the center of the computer screen. The bars were 1 cm by 8 cm, and each bar was presented for 500 ms, with an inter-stimuli interval of 250 ms. The order the red and white bars was random. Participants were asked to press a button using their left thumb on the response pad each time they saw a red bar. In each condition that included the Visual Detection task (see below), there was a total of 480 red bar targets presented.

2.3.3. Dual-task conditions

In the 3 divided attention conditions, participants were asked to perform both tasks simultaneously under 3 conditions of attentional allocation priority. In the 50%–50% condition, participants were told to allocate 50% of their attention to each task. In the 80% equation condition, participants were told to allocate 80% of their attention to the alphanumeric equation task and 20% of their attention to the visual detection tasks. In the 80% detection condition, participants were told to allocate 80% of their attention to the visual detection task and 20% of their attention to the alphanumeric equation task.

Each session (pre/post-training) included 4 blocks of trials, each comprised of the 5 conditions: focused-equation, focused-detection, 50%–50%, 80% equation, and 80% detection (Eq100, Det100, 5050, Eq80, Det80). In each block, 24 trials from each condition were presented sequentially in a single condition “mini-block”. Accordingly, there were a total of 120 trials in each block (24 per condition) and 96 trials for each condition over 4 blocks. A visual representation of the study design is presented in Fig. 1.
2.4. Training protocol and conditions

There were 3 training groups: single-task training (single), fixed divided attention training (fixed), and variable divided attention training (variable). To avoid training specific alphanumeric relationships during the training sessions, the part of the alphabet used for the alphanumeric equation training was from N to Z (not A–M). Participants trained on PC computers and responded to the tasks on the keyboard. For the alphanumeric equation task, participants pressed the “F” key with the left index finger for incorrect equations, and the “J” key with the right index finger for correct equations. For the visual detection task, participants pressed the space bar with their thumb each time they saw a red bar. Each training session comprised of 260 trials spread across 13 blocks. The specific content of each block depended on the training condition of the participant, described in the following sections.

2.4.1. Single-task training (single)

Participants in this group were asked to practice the visual detection task and the alphanumeric equation verification task separately. Each day, participants completed 6 blocks for 1 task and 7 blocks for the other task, and the number of blocks was alternated across sessions so that overall, each task received the same amount of training. The order of tasks alternated within a session and the overall order (i.e., visual detection first or equation verification first) was counterbalanced across participants.

2.4.2. Fixed divided attention training (fixed)

Participants were asked to complete both tasks simultaneously for 9 of the 13 blocks. They were instructed to deploy an equal amount of attention to each task with the following instruction: “You will now have to perform two tasks simultaneously”; however, no specific indication of attentional allocation was provided. No feedback on their performance was provided. To assess baseline performance in each task, participants completed each task in isolation at the beginning and end of each daily session (blocks 1–2 and 12–13).

2.4.3. Variable divided attention training (variable)

Participants were asked to complete the 2 tasks simultaneously for 9 blocks in each session; however, their deployment of attention varied between the blocks. For 3 of the blocks, participants were asked to deploy more of their attention to the equation verification task with the following instruction, “Now you will have to allocate 80% of your attention to the Equation task, and 20% to the Detection task.” For 3 blocks, participants were told to deploy more of their attention to visual detection task, with the same instructions, but with the tasks reversed. For 3 blocks, participants were told to divide their attention equally between the 2 tasks. To assess baseline performance in each task, participants completed each task in isolation at the beginning and end of each session (blocks 1–2 and 12–13). After each block when attention was divided, participants were given information about their performance to adjust their
attentional emphasis on the next block and ensure they were deploying attention correctly (no feedback was provided in the baseline conditions).

2.5. ERP recording and analysis

Neuroelectric brain activity was digitized continuously from 72 active electrodes (10–20 placement) at a sampling rate of 250 Hz, with a high-pass filter set at 0.1 Hz, using a Biosemi ActiveTwo system (Biosemi, Inc, Netherlands). Four electrodes were placed bilaterally on the earlobes and at mastoid sites, and 4 more were placed around the eyes to monitor eye movements (LO1, LO2, SO2, and IO2). All averages were computed using Brain Electrical Source Analysis (version 5.2). The analysis epoch included 200 milliseconds of prestimulus activity and 1000 milliseconds of poststimulus activity. Continuous EEG was averaged separately for each condition, into 10 ERPs; pretraining: Eq100pre, Det100pre, 5050pre, Eq80pre, Det80pre, and posttraining: Eq100post, Det100post, 5050post, Eq80post, Det80post. For the dual-task conditions, ERPs were time-locked to the onset of the trial, as it contained both the alphanumeric equation and visual detection stimuli. For the single-task conditions, ERPs were time-locked to the onset of the alphanumeric equation or the visual detection stimulus for each task, respectively. The experimental procedure can be seen in Fig. 1. To remove activity related to ocular movements, prototypical eye blinks and eye movements were identified through a visual inspection of the continuous EEG file. A principal component analysis of these provided a set of components that best explained the eye movements. These components were then decomposed into a linear combination along with topographical components that reflect brain activity. This linear combination allowed the scalp projections of the artefact components to be subtracted from the experimental ERPs to minimize ocular contamination including blinks, and saccades for each individual average with minimal effects on brain activity (Berg and Scherg, 1994). After this correction, trials with greater than 100 μV of activity were considered artefacts, and excluded from further analysis. Averaged ERPs were then low-pass filtered to attenuate frequencies above 40 Hz, and referenced to the linked mastoid. To assess attentional control, N200 amplitude was quantified over 18 fronto-central and midline electrodes (Fz, FCz, Cz, CPz, Pz, PO2, F3, F1, FC3, FC1, C3, C1, F4, F2, FC4, FC2, C4, and C2). The largest N200 peak was at electrode Cz; accordingly, these electrodes were chosen to capture the N200 peak while taking into account individual variability in scalp topography. N200 amplitude was defined as being the largest negative peak between 230–330 ms, and latency was the latency of this peak. Amplitude and latency of the P1 and N1 components were quantified over 9 parieto-occipital electrodes (Pz, POz, O2, PO7, P03, O1, PO8, PO4 and O2) to assess the impact of training on early visual processing. This array of electrodes was chosen to capture the P1 and N1 components while taking into account individual variability in scalp-topography. P1 was quantified as the largest positive peak between 50–150 ms and N1 as the largest negative peak value between 100–200 ms. It is important to note that ERPs recorded during the dual-task conditions were responses to both tasks because the behavioral tasks were occurring simultaneously. All ERPs were analyzed using a mixed design analysis of variances (ANOVAs) that included testing session (Pre, Post), attention condition (Eq100, Det100, 5050, Eq80, and Det80) and electrode as within-subject factor, and training group (single, fixed, and variable) as a between-subject factor. Multiple electrodes were used to ensure a stable and reliable estimate of the ERP, accordingly, main effects and interactions with electrode are not reported.

2.6. Sociodemographic, neuropsychological, and behavioral data analysis

To verify that the groups were equivalent after randomization, separate 1-way ANOVAs were used to compare demographic (i.e., age, gender and level of education), cognitive (i.e., similarities and digit coding), and neuropsychological assessments (i.e., MoCA and GDS-15) between the 3 groups.

To determine the training effect on the attentional task, we analyzed performance on each of the focused attention and divided attention tasks separately. For the focused attention conditions (i.e., Eq100, Det100), accuracy (percentage of correct responses) and reaction time (RT) were analyzed separately using a mixed design ANOVA that included training group (single, fixed, and variable), and testing session (pre and post) as factors. The ability to flexibly allocate attention was determined by analyzing training-related change in performance on each task during the 3 dual-task conditions in relation to the task instructions. Successful attentional flexibility would be reflected by improved performance on the task participants were asked to devote 80% attention to compared with when that task was performed with 20% attentional focus. To quantify this effect, mixed design ANOVAs were calculated separately for accuracy and RT on each task (alphanumeric equation and visual detection) using testing session (pre, post) and attentional condition (20%, 50%, and 80%) as within-subject factors and training group (single, fixed, and variable) as a between-subject factor.

To determine if training-related changes in the N200 activity were related to training-related task-performance, we calculated correlations between the training-related change in N200 and the training-related change in task performance. Given the number of possible correlations in this analysis, we chose to focus on a theoretically driven subset of our data. Accordingly, we focused only on the 2 conditions where attention was modulated toward a certain task, that is the Det80 and Eq80 conditions. A previous behavioral study from our laboratory revealed that the Det80 condition was the most sensitive to post-training improvements in attentional control because participants had more difficulty allocating attention to the detection task before training (Bier et al., 2014). To ensure that these results were specific, we also tested the Eq80 condition where attention was modulated toward a more difficult task. Given the relatively short training period and initial difficulty with allocating attention to the detection task, it is likely that the Det80 condition would be most susceptible to training-related change, whereas the Eq80 condition would not. First, we calculated the difference after training (i.e., pre – post) for N200 amplitude and latency, and accuracy and RT for both the alphanumeric equation task and the visual detection task. Next, we calculated correlations between the 2 neurophysiological measures, and the 4 behavioral measures in each of the 2 conditions.

3. Results

3.1. Demographic information and neuropsychological assessments

Participant demographics and their performance on the cognitive and neuropsychological assessments are presented in Table 1. The 3 groups did not differ on any of these measures.

3.2. Behavioral performance—focused attention conditions

Performance during the focused attention conditions is presented in Fig. 2. For the alphanumeric equation task, accuracy improved after training, $F(1, 34) = 52.29, p < 0.001$, and the improvement was similar in all 3 groups as the main effect of
training group and its interaction with session were not significant ($p = 0.67$ and 0.67, respectively). Similarly, RTs in the alphanumeric verification task decreased after training, $F(1, 34) = 38.91$, $p < 0.001$, and the improvement was similar in all 3 groups as the main effect of training group and its interaction with session were not significant ($p = 0.94$ and 0.85, respectively). A similar pattern of results was observed for the visual detection task under focused attention. Accuracy improved after training $F(1, 34) = 6.45$, $p = 0.016$, and the improvement was similar in all 3 groups, as the training group by session interaction was not significant ($p = 0.95$). Overall, visual detection accuracy was lowest in the single group, $F(2, 34) = 3.51$, $p = 0.041$, compared with the fixed and variable groups ($p = 0.028$ and 0.031, respectively), but this effect did not interact with session. RTs for the visual detection task decreased after training, $F(1, 34) = 4.74$, $p = 0.036$, and the improvement was similar in all 3 groups as the main effect of training group and its interaction with session were not significant ($p = 0.31$ and 0.43, respectively).

3.3. Behavioral performance—modulation of attention on visual detection task during dual-task conditions

During divided attention, visual detection accuracy improved as attentional allocation instruction focused on this task $F(2, 66) = 38.95$, $p < 0.001$ and also improved after training, $F(1, 33) = 24.78$, $p < 0.001$ (Fig. 3A). Most critical, the 3-way interaction between training group, session, and attention condition was significant $F(6, 102) = 3.00$, $p = 0.025$. Follow-up simple 2-way interactions revealed a significant session by attentional condition interaction for the variable group $F(2, 24) = 7.22$, $p < 0.004$ that was not significant for the other 2 groups ($p > 0.5$ for both). In the variable group, follow-up pairwise comparisons revealed that accuracy for the visual detection task increased after training for the Det80 and 5050 condition ($p < 0.001$ for both). In other words, after training, visual detection accuracy improved when participants in the variable group were instructed to allocate greater attentional resources to the visual detection task, whereas this was not the case for the other groups. To best illustrate this training-related gain in the variable group, the difference between pre-training and post-training accuracy is presented in Fig. 3B.

### Table 1

Demographics.

<table>
<thead>
<tr>
<th></th>
<th>Single</th>
<th>Fixed</th>
<th>Variable</th>
<th>$p$ value</th>
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</thead>
<tbody>
<tr>
<td>N</td>
<td>12</td>
<td>11</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Age</td>
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<td>71.54 (6.30)</td>
<td>69.01 (4.66)</td>
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<tr>
<td>Gender</td>
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<td>1.42 (0.51)</td>
<td>1.31 (0.48)</td>
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</tr>
<tr>
<td>Education</td>
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<td>15.08 (2.68)</td>
<td>15.31 (4.11)</td>
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</tr>
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<td>MoCA</td>
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<td>27.61 (1.98)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Similarities</td>
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<td>22.08 (3.00)</td>
<td>22.54 (3.53)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Digit code</td>
<td>66.23 (13.70)</td>
<td>59.75 (9.52)</td>
<td>65.61 (8.23)</td>
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</tr>
<tr>
<td>GDS/15</td>
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<td>0.92 (1.24)</td>
<td>2.08 (3.50)</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

Mean (standard deviation).
Key: GDS, Geriatric Depression Scale; MoCA, Montreal Cognitive Assessment; n.s., not significant.
Reaction times for the visual detection task decreased as attentional allocation increased on the visual detection task, $F(2, 66) = 17.55, p < 0.001$ and also decreased after training, $F(1, 32) = 12.49, p < 0.001$ (Fig. 3C). The 3-way interaction between training group, session, and attentional condition was marginally significant $F(4, 66) = 2.32, p = 0.066$. Follow-up simple 2-way interactions revealed that the session by group interaction was significant for the Det80 condition, $F(2, 33) = 3.31, p = 0.049$, marginally significant for the 5050 condition $F(2, 33) = 3.05, p = 0.061$, and not significant for the Eq80 condition ($p = 0.97$). In the Det80 and 5050 condition, the interaction was driven by a larger decrease in RT for the variable group compared with the other 2 groups. To best illustrate this training-related gain in the variable group, the difference between pretraining and posttraining RT is presented in Fig. 3D.

3.4. Behavioral performance—modulation of attention on alphanumeric equation task

Accuracy on the alphanumeric equation task improved as attention was modulated toward the alphanumeric equation task, $F(2, 66) = 11.39, p < 0.001$ and increased after training, $F(1, 32) = 12.49, p < 0.001$ (Fig. 4A). The 3-way interaction between training group, session, and attentional condition was not significant $F(2, 66) = 1.01, p = 0.45$ (Fig. 4C). This effect was similar across the 3 training groups as the session by training group and session by training group by attentional condition interactions were not significant ($p = 0.39$ and 0.45, respectively). Finally, the post-training decrease in RT was larger as attention was increasingly allocated toward the alphanumeric equation task, although the session by attentional condition interaction failed to reach significance $F(2, 66) = 2.08, p = 0.13$.

3.5. ERP data analysis

The N200 is presented at electrode Cz in Fig. 5, and the P1 and N1 are presented at electrode PO7 in Fig. 6. For all ERP effects, the magnitude was quantified over multiple electrodes (see Section 2); these electrodes were chosen as being representative of the overall effect. In both figures, ERPs are separated by training group, attentional condition, and testing session.

3.5.1. N200—peak amplitude

Overall, the peak amplitude of the N200 was larger during the posttraining session, $F(1, 33) = 7.29, p = 0.011$. Given our a priori
hypotheses about the impact of group on N200 amplitude, we measured this effect separately in each group, despite the finding that the testing session by group and testing session by group by attention condition interactions were not significant, $F(2, 33) = 1.7, p = 0.2$ and $F(8, 132) = 1.2, p = 0.3$, respectively. In the variable group, the N200 was larger after training, $F(1, 12) = 11.2, p = 0.006$. Interestingly, after training, N200 amplitude followed a quadratic trend in the variable group, $F(1, 12) = 7.2, p = 0.02$. This analysis demonstrates that the N200 amplitude was largest during the 3 divided attention conditions and smallest during the focused attention conditions. This trend was not significant before training ($p > 0.5$), highlighting that the training-related change in N200 amplitude was related to attentional control. There was no significant impact of training on N200 amplitude for either the single or fixed groups, $F(1, 11) = 2.19, p = 0.17$, and $F(1, 10) = 0.11, p = 0.75$, respectively. Overall, the N200 was influenced by attentional condition, $F(4, 132) = 3.39, p = 0.011$, and this was due to the N200 being smallest during the Det100 condition compared with the other 4 conditions ($p < 0.05$ for all). Finally, the interaction between attentional condition and testing session was not significant ($p = 0.27$).

3.5.2. N200–peak latency

The N200 latency was impacted by attentional condition, $F(4, 132) = 3.96, p = 0.005$, and followed a quadratic trend, with the latency being shortest for the divided attention conditions and longest for the detection and alphanumeric equation tasks when done in isolation $F(1, 33) = 10.05, p = 0.003$. There was a marginally significant interaction between attentional condition and testing session $F(4, 132) = 2.29, p = 0.063$ that was driven by a post-training reduction in N200 latency for the Det80 condition only (284.3–276.9 ms). The other 4 attentional conditions all had post-training changes in N200 latency that was less than 2.2 ms. The impact of testing session, group, the group by attentional condition interaction, the group by testing session, and the 3-way interaction were not significant ($p > 0.2$ for all).

3.5.3. P1–peak amplitude

There was no difference in P1 peak amplitude after training in all groups, as the main effect of testing session and its interactions with group were not significant ($p = 0.19$ and 0.17, respectively). P1 peak amplitude was impacted by attentional condition, $F(4, 132) = 21.84, p < 0.001$, and this was due to a linear increase in P1 amplitude as participants increasingly focused their attention on the alphanumeric equation task, $F(1, 33) = 41.44, p < 0.001$.

3.5.4. P1–peak latency

P1 latency decreased after training, $F(1, 33) = 6.14, p = 0.019$, and this change was similar in all groups as the interaction with group was not significant ($p = 0.37$). P1 peak latency was impacted by attentional condition, $F(4, 132) = 10.3, p < 0.001$, with P1 latency being longer in the Det100 condition compared to all other conditions ($p < 0.001$ for all).

Fig. 4. Behavioral performance for the alphanumeric equation task during dual-task conditions separated by group (single: single-task training in blue; fixed: fixed attention training in red; and variable: variable attention training in black). Accuracy increased, and reaction-time decreased after training, and this effect was similar across all groups. (A) Accuracy, as a function of the attentional condition. (B) Training-related accuracy gain (post-training–pre-training) as a function of the attentional condition. (C) Reaction time (RT) as a function of the attentional condition. (D) Training-related RT gain (post-training–pre-training) as a function of the attentional condition. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)
3.5.5. N1 peak amplitude

The training group by testing session interaction was marginally significant, $F(2, 33) = 2.93, p = 0.067$. Follow-up tests revealed that N1 only increased in amplitude for the single group $F(1, 11) = 7.88, p = 0.017$ and not for the variable ($p = 0.38$) and fixed ($p = 0.62$) groups. Peak N1 amplitude was impacted by attention condition, $F(4, 132) = 15.94, p < 0.001$, and polynomial decompositions revealed a significant linear trend, $F(1, 33) = 22.44, p < 0.001$. N1 amplitude increased the most from the Det100 to Det80 and increased smaller amounts from the Det80 to the 5050 to the Eq80 to the Eq100.

3.5.6. N1 peak latency

N1 latency was impacted by attention condition $F(4, 132) = 14.2, p < 0.001$. Polynomial decompositions revealed a significant linear trend for N1 latency, $F(1, 33) = 17.16, p < 0.001$. N1 latency decreased the most from the Det100 to Det80, and decreased in smaller amounts from the Det80 to the 5050 to the Eq80 to the Eq100. The effect of attentional condition was qualified by a significant interaction with testing session and group, $F(8, 132) = 2.162, p = 0.034$. Follow-up simple 2-way interactions revealed that the attentional condition by testing sessions interaction was significant in the fixed group $F(4, 40) =...
2.65, \( p = 0.047 \), marginally significant in the variable group \( F(4, 48) = 2.37, \ p = 0.066 \), and not significant in the single group \( (p = 0.74) \). Follow-up simple main effects revealed that N1 latency was impacted by attentional condition in the fixed group before training, \( F(4, 40) = 5.2, \ p = 0.002 \), with N1 latency being longest during the Det100 condition. After training, N1 latency was not impacted by attentional condition in the fixed group, \( F(4, 40) = 0.58, \ p = 0.68 \).

3.6. Training-related brain-behavior correlations

To determine if training-related changes in attentional modulation were related to training-related changes in the N200, a series of correlations were calculated for the differences between pretraining and posttraining measurements in relevant conditions. Training-related changes in attentional modulation were expected to be maximal in conditions where participants were instructed to

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**Fig. 6.** (A) Event-related potentials (ERPs) recorded at electrode PO7 separated by group (single: single-task training; fixed: fixed attention training; and variable: variable attention training), and attentional priority. Pre-training ERPs are in blue, and post-training ERPs are in red. The P1 and N1 are labeled on the top right. (B) Amplitude of the N1 in each group, for each condition, before and after training. The N1 increased in amplitude after training in the single group. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)
prioritize 1 task over the other, that is the Det80 and Eq80 conditions. During each of these conditions, we have 4 behavioral measurements, visual detection accuracy and RT, and alphanumeric equation accuracy and RT, yielding a series of 8 bivariate correlations. As can be seen in Fig. 7, a larger training-related increase in N200 amplitude was related to more improvement in visual detection accuracy in the Det80 condition \( r (35) = 0.53, p < 0.001 \). There was however, also a correlation between the training-related gain in N200 amplitude and training-related gain in accuracy during the alphanumeric task during the Det80, \( r (35) = 0.40, p = 0.016 \). Because these 2 tasks were being performed simultaneously, a linear regression was calculated to determine the extent to which each of these measures was related to N200 amplitude. When both accuracy measures were entered simultaneously, only visual detection accuracy remained as a significant predictor of N200 amplitude \( t (35) = 2.71, p = 0.011 \), whereas alphanumeric accuracy was not a significant predictor of N200 amplitude, \( p = 0.21 \). In the Det80 condition, there was no relationship between training-related gain in N200 amplitude and reaction time for either task \( (p > 0.13 \text{ for both}) \). For the Eq80 condition, there was no relationship between training-related gain in accuracy and N200 amplitude, nor RT and N200 amplitude \( (p > 0.2 \text{ for all}) \).

4. Discussion

The main finding from this study was that different forms of attentional training differently impacted event-related brain responses and dual-task performance. The 3 main neurophysiological findings were (1) a training-related enhancement to the N200 in the variable group that was modulated by task demands after training, (2) enhancement to the N1 in the single group, and (3) an earlier P1 in all groups. Behaviorally, accuracy improved and RT decreased in all groups for dual-task and focused attention conditions. Nevertheless, the ability to accurately modulate attention according to task instructions only improved for the variable group, as performance improved in this group on the visual detection task when asked to prioritize this task. Correlations between the training-related gain in visual detection performance and the training-related gain in N200 amplitude demonstrate that the neurophysiological change in the variable group was related to improved task performance. Training people to modulate their level of attention using a dual-task training paradigm resulted in the greatest improvement in attentional control, and this was related to an enhancement of the N200, an ERP related to attentional control.

These findings are consistent with previous work has found that attentional training can enhance the N200 (Eldar and Bar-Haim, 2010; Rueda et al., 2005; Schapkin et al., 2007). Using a visual go-nogo task, Schapkin et al. (2007) found that both performance and N200 amplitude increased over the course of 3 weeks of practice, suggesting an improved ability to compare incoming visual stimuli, and inhibit responses on no-go trials. Using an attentional training program that focused on ignoring salient stimuli, Eldar and Bar-Haim (2010) found that the N200 amplitude increased in response to the ignored stimuli, likely reflecting increased ability to inhibit a behavioral response. Finally, Rueda et al. (2005) trained a group of children on a go-nogo task and found that task performance and the N200 were enhanced during a visual discrimination task with incongruent distractors, likely because training improved the ability to ignore distractor stimuli. Using a visual discrimination task, Wang et al. (2010) reported that learning to make a difficult perceptual judgment increased N200 amplitude, whereas learning to make an easier perceptual judgement had no impact on the N200. Accordingly, the authors associated this change as reflecting an increased ability for perceptual discrimination; however, given the latency of the N200, it is likely that any perceptual discrimination processes indexed by the N200 are related to active inhibitory processes and not visual discrimination that is more likely indexed by the N1 (Vogel and Luck, 2000).

More importantly, these studies demonstrate that the N200 is susceptible to various forms of cognitive training that require some sort of cognitive inhibition, suggesting that the N200 reflects inhibitory processes. In support of this hypothesis, a number of studies have shown that the frontal N200 increased in amplitude for no-go trials on go-nogo tasks (Heil et al., 2000; Jodo and Kayama, 1992; Pfefferbaum et al., 1985; Van Gaal et al., 2011). Critically, Van Gaal et al. (2011) found that the N200 amplitude was specifically correlated with the efficiency of automatic inhibitory control.

Based on this interpretation of the N200, the enhancements observed in the variable group are likely related to the ability to control attention, especially considering that the post-training N200 was largest in the divided attention conditions. These changes may reflect a training-related increase in the ability to quickly and efficiently inhibit cognitive processes related to the task that should not be prioritized. This would allow for more efficient task-prioritization when performing 2 tasks simultaneously. Two lines of evidence from our study provide further support this proposal. First, visual detection accuracy improved and RT decreased in the variable group, and these improvements were in line with task demands that required modulation of attention (See Fig. 3B and D). That is, for the variable group only, accuracy and RT for the visual detection task improved the most when asked to allocate 80% of their attention to the visual detection task. The training-related improvement was smaller when asked to divide attention equally between the 2 tasks, and smaller still when asked to allocate only 20% of their attention to the visual detection task. Second, the enhancement of the N200 was correlated with this improved performance during the Det80 condition, and the N200 was enhanced in the variable group.

The training-related enhancement in the ability to prioritize a task is therefore likely related to enhanced inhibitory control. Age-related decline in inhibitory control is considered to be one of the hallmarks of age-related cognitive decline (Hasher et al., 2007). One of the main functions of inhibition during attention control is the process of restraint, which usually involves inhibition of a prepotent response (Hasher et al., 2007). In the present study, participants who were trained to modulate their attention (i.e., Variable training), improved their performance on the visual detection task in line with task-prioritization demands. It is possible that the
benefit of variable training was due to an enhanced ability to inhibit a prepotent response to the alphanumeric equation task. Previous work from our laboratory has shown that untrained older adults tend to sacrifice performance on the easier visual detection task to maintain performance on the more difficult alphanumeric equation task (Bier et al. 2014). The current results suggest that for the variable group, the natural tendency to focus on the alphanumeric equation task was inhibited, so that the visual detection task could be performed at a higher level. This would explain why the variable group improved on the visual detection task most during the Det80 condition, and least during the Det20 condition. The enhanced N200 and improved ability to accurately modulate attention after training in the variable group, likely reflects this enhanced inhibitory control. Indeed, previous findings have tied the N200 to inhibitory control (e.g., Van Gaal et al., 2011). The enhancement to the N200 reflects plasticity of the aging attentional control system. That is, variable training may have fostered the development of new neural connections or greater neural synchrony that enhanced the ability to inhibit responses to a task that would normally attract attention. These neuroplastic changes would result in a more flexible attentional control system indexed by an enhanced N200. At the same time, other studies have tied the N200 to conflict monitoring (Donkers and Boxtel, 2004). If the N200 in the present study was related to conflict monitoring, one would predict a reduction in N200 amplitude after training because training would reduce the conflict between the 2 tasks, and thus decrease the conflict response. The posttraining increase in amplitude of the N200 suggests that it was inhibitory control that was enhanced. Accordingly, if learning to divide and modulate attention can enhance inhibitory function in older adults, it provides strong support for using this type of cognitive training to alleviate age-related decline in attentional control.

This finding is particularly interesting as a previous study from our laboratory that used a similar testing paradigm, but measured the blood oxygenation level dependent (BOLD) signal using functional magnetic resonance imaging (fMRI), revealed posttraining enhancements in the right superior and middle frontal gyri (BA 10) in the variable group (Belleville et al., 2014). Given that the testing protocols were almost identical, it is highly likely that the enhancement in the frontal lobes is related to the enhanced N200. Support for this hypothesis comes from EEG studies that have localized the N200 from no-go trials in a go-no-go task (i.e., inhibitory responses) to frontal areas including BA 10 (Lavric et al., 2004) and that training on a go-no-go task enhanced activity in prefrontal brain regions (Kelly et al., 2006). These regions are likely associated with orchestrating basic executive functions that are critical for metacognition (Stuss, 2011). Findings from the present study suggest that these regions are likely related to active inhibitory processes that allow for dual-tasks to be performed in line with prioritization demands. The general trend that N200 amplitude increased as attention was required to be shifted toward the more difficult equation task supports this proposal.

Although the N200 was enhanced in the variable group, the N1 was enhanced in the single group. The N1 is related to making visual discriminations (Vogel and Luck, 2000). It is therefore likely that the enhanced N1 in the single group is related to improved visual discrimination that leads to improved perceptual fluency. It has been shown that familiarity with a stimulus will speed responses to that stimulus (e.g., Johnston et al., 1985). While training on each task individually, structures in the ascending visual pathway may have become primed for the visual presentation of each task; this priming may not have occurred for the fixed and variable groups because these training included both stimuli and always required attentional control. Support for this idea is based on a model proposed by Oppenheimer (2008), which suggests that the added cognitive demands in the fixed and variable groups would impact the development of perceptual fluency. Further support for this proposal comes from the fMRI study from our laboratory that used the same training paradigm. In this study, the single group had reduced activation in the thalamus, and inferior and middle frontal gyri after training (Belleville et al., 2014). The reduction of thalamic activity could be interpreted as reflecting more efficient transfer of visual information as it travels via the thalamus to primary visual areas. In turn, this facilitation would enhance the basic visual representation, and this could result in an enhanced N1. The enhanced visual representation in the present study would then facilitate downstream processing in frontal regions, resulting in the decreased activations observed in frontal regions (Belleville et al., 2014).

These results highlight the differential impact of training format on performance. They indicate that training individual tasks can improve performance on the same tasks when performed simultaneously; however, this improvement is not as large as when trained to divide and modulate attention. It is therefore likely that to improve the ability to control attention correctly, one must practice modulating attention. Supporting this idea, we found that the variable training was the only training format that improved attentional control. During the divided attention conditions, participants in all groups had improved accuracy and RT; however, only the variable group had improved accuracy and RT on the visual detection task in a pattern that was in line with the prioritization demands of each condition.

Although the findings from the study are promising, there are a number of limitations that highlight the need for further research into the possibility of using training to improve attentional control in older adults. The first is that transfer to nontrained tasks (i.e., far-transfer) was not measured. Demonstrating far-transfer is critical if cognitive training protocols are going to be translated into rehabilitation programs for older adults. Although, the present study controlled for stimulus familiarity by using different stimulus sets during the training and testing phases of the study, it did not measure an untrained attentional control task. To make the claim that learning to modulate attention according to task demands is the best way to improve attentional control, a study should also perform pre- and post-training assessments on a nontrained attentional control task. It is also important to note that the improved attentional control was limited to performance on the visual detection task, as post-training improvement on the alphanumeric equation task was not modulated by task demands. It is likely that the short training session contributed to this effect. The alphanumeric equation task was more difficult than the visual detection task and therefore would require a longer training session to develop the ability to accurately modulate attention in line with task demands. Finally, it is important to highlight that the group differences in N200 amplitude were statistically weak. There are a number of possible reasons for the weak statistical effects, including a short-training protocol (6 hours), small sample size, and intersubject variability on the success of the training. Intersubject variability in the success of cognitive training programs is emerging as a critical issue. It is likely that any format of training will be successful with some participants and unsuccessful with others. When samples are small, these individual differences can be hard to identify, highlighting the need to run randomized control studies that use cognitive training on larger samples. With larger samples, individual differences, including, but not limited to, personality, cognitive status, physical health, and so forth can be identified and used to determine what type of individual is most likely to benefit from a given form of cognitive training. These types of studies will be critical as cognitive rehabilitation becomes a more common treatment for age-related deficits in cognition.
5. Conclusion

Data from the present study demonstrate that the ability to modulate attention according to task demands can be improved in older adults, when appropriate training is used. This finding has significant implications for healthy aging, as attentional control is known to decline with age. Most critical, our findings suggest that the aging brain remains plastic and modifiable via experience. Importantly, inhibitory processes that are known to decline with age were likely improved by learning to modify how attention is divided. We demonstrated this by showing that performance improved in the variable group, selectively for the simpler of the 2 tasks (i.e., visual detection) in conditions when participants were asked to modulate their deployment of attention. Moreover, the N200 was specifically sensitive to variable-priority training, and was largest in the post-training divided attention conditions. Given that the N200 has been found to be sensitive to a wide range of training tasks across the lifespan, including inhibitory processes, the N200 is likely a critical neurophysiological index of attentional control. Future research should focus on using variable priority training in people with specific disabilities in their ability to orient and modulate their attention accurately, and in healthy adults in real-life situations that require rapid and accurate modulation of attention.

Disclosure statement

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