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

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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.

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

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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 found benefits to attentional control from fixed-training protocols. Bherer 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 unlikley 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 Boxtel (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 orientating is reduced and delayed in older adults (Lorenzo-López 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