Age differences in the Attention Network Test: Evidence from behavior and event-related potentials

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ABSTRACT

The Attention Network Test (ANT) is widely used to capture group and individual differences in selective attention. Prior behavioral studies with younger and older adults have yielded mixed findings with respect to age differences in three putative attention networks (alerting, orienting, and executive control). To overcome the limitations of behavioral data, the current study combined behavioral and electrophysiological measures. Twenty-four healthy younger adults (aged 18–29 years) and 24 healthy older adults (aged 60–76 years) completed the ANT while EEG data were recorded. Behaviorally, older adults showed reduced alerting, but did not differ from younger adults in orienting or executive control. Electrophysiological components related to alerting and orienting (P1, N1, and CNV) were similar in both age groups, whereas components related to executive control (N2 and P3) showed age-related differences. Together these results suggest that comparisons of network effects between age groups using behavioral data alone may not offer a complete picture of age differences in selective attention, especially for alerting and executive control networks.

1. Introduction

Selective attention is thought to be comprised of at least 3 functionally distinct neural networks of alerting, orienting, and executive control (Posner & Petersen, 1990; revised by Petersen & Posner, 2012). Alerting is characterized as a state of enhanced vigilance or preparedness to respond to incoming information. This network is believed to map onto the norepinephrine arousal (LC-NE) system, with the detection of alerting signals leading to activity in the locus coeruleus, which projects to areas in the frontal cortex, as well as parietal areas of the dorsal visual pathway (Aston-Jones & Cohen, 2005; Marzo, Totah, Neves, Logothetis, & Eschenko, 2014; Petersen & Posner, 2012; Rajkowski, Kubiak, & Aston-Jones, 1994). The orienting network is involved in the shifting of attention to particular spatial locations. Areas associated with this network include the temporoparietal junction (TPJ), frontal eye fields (FEFs), and superior parietal cortex. Activation of this network may depend on whether shifts in attention are automatic (exogenous) or volitional (endogenous; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Mayer, Dorflinger, Rao, & Seidenberg, 2004). Acetylcholine appears to be the neurotransmitter most involved in the orienting response (Klinkenberg, Sambeth, & Blokland, 2011; Stewart, Burke, & Marrocco, 2001). Finally, the executive control network involves top-down processes involved in detecting conflict and inhibiting distracting information. Areas of the prefrontal cortex (PFC) and anterior cingulate cortex (ACC) play a key role in executive functioning, with dopamine regulation being particularly critical for the efficiency of this network (Crottaz-Herbette & Menon, 2006; Fan et al., 2005; Floresco & Magyar, 2006; Funahashi & Andreau, 2013; Lumme, Aalto, Ilonen, Nagren, & Hietala, 2007).

These networks are often studied using the Attention Network Test (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002), which combines an arrow-flanker task (Eriksen & Eriksen, 1974) with an attentional cuing paradigm (Posner, 1980). Alerting is measured by comparing reaction times (RTs) for responses to targets preceded by a double cue, serving as a warning, to those in which no warning cue is provided. The orienting network is measured as the difference in RT for responses aided by a valid spatial cue compared to those preceded by a spatially uninformative (center) warning cue. Lastly, executive control is examined by comparing RT for incongruent targets to those for congruent targets, also referred to as a flanker interference effect.

The ANT has been used to assess the efficiency of the attention networks in a wide range of populations (e.g. Ishigami, Fisk, Wojtowicz, & Klein, 2013; Kratz et al., 2011; Togo, Lange, Natelson,
Anllo-Vento, 1998). These components likely mark an early stage of CNV, which is an orienting response to the cue, and the latter marking preparation for a motor response (Gomez, Marco, & Grau, 2003; Klorman & Bentsen, 1975). In general, increased negativity of CNV is associated with faster responding to target information (Fan et al., 2007; Linssen et al., 2011).

The N2 component, present at fronto-central electrode sites, reaches peak amplitude between 250 and 350 ms following the presentation of target stimuli. Conflict monitoring theory positions the ACC as the mechanism underlying N2, working to recruit top-down resources when conflict is detected to improve stimulus evaluation (Groom & Cragg, 2015; see Botvinick, Cohen, & Carter, 2004; Larson, Clayson, & Clawson, 2014, for reviews). Supporting this notion, a number of studies that have combined ERP methods with flanker conditions similar to those used in the ANT have demonstrated that incongruent flankers produce significantly more negative amplitudes than congruent flankers at fronto-central sites (e.g. Clayson & Larson, 2011; Grützmann, Riesel, Klawohn, Kathmann, & Endrass, 2014; Purmann, Badde, Luna-Rodriguez, & Wendt, 2011). However, ACC activity generated during N2 may actually reflect an evaluation of the possible outcomes rather than conflict detection, as recently proposed under the predicted response model (Brown, 2013).

P3, which is generated along midline electrodes, reaches peak amplitude 250–500 ms after the presentation of target stimuli. The P3 component is comprised of at least two subcomponents: a frontally generated P3a involved in novelty detection, and a medial temporal lobe generated P3b involved in stimulus evaluation (for a review, see Polich, 2007). While P3 is elicited by a number of executive control tasks (e.g. Galashan, Wittfoth, Fehr, & Herrmann, 2008; Nakata, Sakamoto, & Kikigi, 2010; Shen, 2006), under flanker conditions, incongruent targets lead to increased peak latency and reduced amplitude of the P3 at central and parietal sites, relative to congruent targets (Clayson & Larson, 2011; Potts, 2011; Purmann et al., 2011). The increased latency may reflect the use of more time to evaluate the target (Falkenstein, Hoehnseib, & Hoormann, 1994; Verleger, Jaskowski, & Wascher, 2005), and the reduction in amplitude may be related to greater response inhibition (Groom & Cragg, 2015).

To our knowledge, only two studies (i.e. Galvao-Carmona et al., 2014; Neuhaus, Urbanek, et al., 2010) have studied visual attention in healthy adult populations by combining the ANT with ERP methods. Galvao-Carmona et al. (2014) used a modified version of the standard ANT which included a longer cue-target interval, and did not include a double cue condition. Neuhaus, Urbanek, et al. (2010) described effects of alerting and orienting on N1 at the time of the target, with larger amplitudes in the double cue condition than the no cue condition, and in the spatial cue condition compared to the center cue condition. These effects were largest at parietal and occipital sites, respectively. N1 at the time of the cue was also modulated by cue condition, but the effects appeared to be affected more by the visual features of the cue itself, rather than network effects. Additionally, target P3 amplitude was reduced parietally under the incongruent target condition compared to the congruent target condition. These effects were largely replicated by Galvao-Carmona et al. (2014), though the orienting effect was not found for N1, which the authors suggest may have been diminished by the longer cue-target interval. Further, unlike Neuhaus, Urbanek, et al. (2010); Neuhaus, Trempler, et al. (2010) and Galvao-Carmona et al. (2014) also investigated P1 and CNV. P1 amplitude was increased for targets preceded by a spatial cue relative to those preceded by no cue or a center cue at parieto-occipital sites. Lastly, the late stage of CNV appeared to be affected by alerting as the

Event-related potentials (ERPs), which allow for observations of neural activity in response to visual stimuli with high temporal resolution, may prove to be an avenue to expand our understanding of age differences in selective visual attention. As recent studies have demonstrated (e.g., Galvao-Carmona et al., 2014; Neuhaus, Urbanek, et al., 2010), ERPs generated during the ANT show differential effects of attention networks at various scalp locations, with such modulations varying between populations (e.g. Neuhaus, Trempler, et al., 2010). In particular, posterior P1 and N1 components, as well as the contingent negative variation (CNV), may be involved in both alerting and orienting, whereas fronto-central N2 and midline P3 components seem to be involved executive control processes.

P1 and N1 components, present at posterior scalp regions, have been identified as two of the earliest markers of visual attention (P1 onset around 80–100 ms post stimulus presentation, followed by N1). P1 has been localized to the extrastriate visual cortex, whereas multiple generators in occipital and parietal regions seem to underlie N1 (Clark, Fan, & Hillyard, 1994; Eimer, 1998; Hillyard & Anllo-Vento, 1998). These components likely mark an early visual processing of stimuli properties that is enhanced under conditions of heightened attention, as they tend to increase in amplitude when visual stimuli are presented to an attended to location compared to a non-attended to location (Eimer, 1998; Mangun, 1995; Talsma, Slagter, Nieuwenhuis, Hage, & Kok, 2005), though, this is not always true of P1 (see Doallo et al., 2004; McDonald, Ward, & Kiehl, 1999).

CNV is a slow negative wave observed maximally at central and fronto-central sites along the midline (i.e. Cz and FCz) in the interval between a warning signal and imperative target. A number of regions have been identified in the generation of CNV, including the PFC, ACC, basal ganglia, and supplementary motor area (SMA; Barea & Rektor, 2001; Fan et al., 2007; Rosahl & Knight, 1995). An early and a late stage of CNV can be distinguished, with the former often described as an orienting response to the cue, and the latter marking preparation for a motor response (Gomez, Marco, & Grau, 2003; Klorman & Bentsen, 1975). In general, increased negativity of CNV is associated with faster responding to target information (Fan et al., 2007; Linssen et al., 2011).
amplitude of this component was larger in center cue condition than the no cue condition during the 300 ms prior to target onset, whereas both stages of CNV benefited from orienting as the amplitude was greater at all observed time points in the spatial cue condition compared to the other cue conditions. While neither study reports effects of target congruency on N2 amplitude or P3 latency, healthy controls in Neuhaus et al. (2007) did show congruency effects on P3 latency, but not N2 amplitude.

While the studies described thus far shed light on the electrophysiological markers of the ANT, to our knowledge no study has capitalized on ERP markers to characterize age differences in attention networks. Considering growing evidence that older adults may recruit additional brain regions, especially in frontal areas, during cognitive performance (e.g. Davis, Dennis, Daselaar, Fleck, & Cabeza, 2008; Kopp, Lange, Howe, & Wessel, 2014; Langenecker & Nielson, 2003; Li, Gratton, Fabiani, & Knight, 2013), it seems likely that electrophysiological patterns associated with attention networks change with age. This is particularly important given that behavioral measures may not always be sensitive to these changes. As shown across a number of cognitive domains, compensatory recruitment of alternative neural networks sometimes allows older adults to maintain behavioral performance similar to that of younger adults (e.g. Cabeza, Anderson, Locantore, & McIntosh, 2002; Gutchess et al., 2005; Hsieh & Fang, 2012).

Despite the lack of studies investigating the electrophysiological markers of the ANT in older adults, insight into how the ERPs generated during this task might differ between younger and older adults has been offered by previous research that has focused on individual attention networks. Of the three networks, age differences related to executive control have received the most attention concerning the P1 at the target, and CNV during the interval between the cue and target. In contrast, executive control effects were expected to be present on the fronto-central N2, and midline P3 component at the time of response. Further, it was predicted that behavioral age differences in the attention networks would also be detectable in these ERP components.

2. Method

2.1. Participants

Twenty-four younger adults and 26 older adults participated in the present study. Younger adults were recruited via flyers posted around the campus of Ryerson University in Toronto, Ontario. Older adults were recruited through the Ryerson Senior Participant Pool. One older participant had to be excluded for use of anti-depressant medication. All other participants reported no use of psychoactive medications, no uncorrected vision and hearing problems, and no other major health problems including neurological and psychiatric disorders. Participants were screened using the Mini Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975) to assess possible dementia-related cognitive impairment. Participants were excluded from analysis if they scored below 26 out of a possible 30 points, which was the case for one older adult. Demographic characteristics and group differences on a number of neuropsychological measures for the final sample are presented in Table 1. Written informed consent was received from each participant. Participants received $12/h in exchange for their participation. In addition, they received a bonus that depended on their performance during the experimental task. The average bonus was $18.65 (SD = 3.12), and did not differ significantly for the two age groups.

2.2. Stimuli and apparatus

The experimental task (see Fig. 1) was administered using Presentation Software (version 16.5; Neurobehavioral Systems;
Berkeley, CA) on a 17-in. Viewsonic VE175-2 monitor being operated by a Windows-based computer. All stimuli appeared in white against a black background. Participants used two keys of a Microsoft keyboard to respond to the direction of a central arrow. Participants pressed “x” with their left index finger if the arrow pointed left, and “” with their right index finger if the arrow pointed right. These response keys were marked by red stickers.

The central arrow to which participants were asked to respond appeared directly above or below a central fixation cross and was flanked to the right and left either by two arrows facing in the same (congruent) or opposite (incongruent) direction, or by two horizontal lines (neutral). At a viewing distance of 60 cm, the central arrow subtended a visual angle of 0.76°. The total subtended visual angle of the central arrow with the four flankers was 3.8°. Targets were presented 0.9° above or below the fixation cross.

Further, targets were preceded by one of four cue conditions: no cue, double cue, center cue, or spatial cue. For the no cue condition, no warning stimuli were presented to participants. In the double cue condition, an asterisk appeared both above and below the central fixation. In the center cue condition, an asterisk briefly replaced the central fixation cross. Lastly, in the spatial cue condition, an asterisk appeared either directly above or below the central fixation cross in the position where the target would later occur. Each of the asterisk cues subtended a visual angle of 0.48°.

Throughout each block, the fixation cross was maintained at the center of the display. For each trial, one of the four cue conditions was presented for 100 ms following a variable period of 400–1600 ms. Target stimuli were presented 400 ms after the cue interval and maintained until a response was made by the participant or until 1700 ms had elapsed.

2.3. Design

The ANT consisted of 6 experimental blocks involving 96 trials each (576 total), in addition to 2 practice blocks of 24 trials. Within each block, all cues (no, double, center, spatial) and all targets (congruent, incongruent, neutral) were presented an equal number of times. In half of the trials, targets appeared above the fixation cross, and below for the remaining trials. Similarly, the direction of the central arrow pointed right in half of the trials and left in the other half. Every cue by target combination, including the various target orientations, was presented twice for each block in a randomized order. Also, in order to keep participants motivated, blocks were associated with potential monetary rewards or losses.

Table 1
Summary of participant characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Younger M (SD)</th>
<th>Older M (SD)</th>
<th>p*</th>
</tr>
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<tbody>
<tr>
<td>N</td>
<td>24</td>
<td>24</td>
<td>–</td>
</tr>
<tr>
<td>N (Females)</td>
<td>15</td>
<td>16</td>
<td>–</td>
</tr>
<tr>
<td>Age, years</td>
<td>21.6 (3.0)</td>
<td>65.1 (5.1)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Age range, years</td>
<td>18–29</td>
<td>60–76</td>
<td>–</td>
</tr>
<tr>
<td>Education, years</td>
<td>15 (1.6)</td>
<td>17 (3.1)</td>
<td>.004</td>
</tr>
<tr>
<td>Mill Hill Vocabulary Scale (MHV)</td>
<td>15.7 (3.6)</td>
<td>22.0 (4.4)</td>
<td>&lt;.001</td>
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<tr>
<td>Digit Symbol Substitution Task (DSST)</td>
<td>88.8 (12.8)</td>
<td>72.1 (10.9)</td>
<td>&lt;.001</td>
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<tr>
<td>Mini Mental State Exam (MMSE)</td>
<td>29.3 (.75)</td>
<td>29.3 (1.0)</td>
<td>.528</td>
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<tr>
<td>Behavioral Inhibition/Behavioral Activation Scales (BIS/BAS)b</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>BIS</td>
<td>21.2 (3.2)</td>
<td>20.0 (2.5)</td>
<td>.169</td>
</tr>
<tr>
<td>BAS drive</td>
<td>10.9 (2.5)</td>
<td>10.0 (2.4)</td>
<td>.187</td>
</tr>
<tr>
<td>BAS fun seeking</td>
<td>13.0 (1.9)</td>
<td>11.1 (2.7)</td>
<td>.007</td>
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<td>BAS reward responsivity</td>
<td>17.5 (2.2)</td>
<td>16.4 (2.1)</td>
<td>.104</td>
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<td>Positive &amp; Negative Affect Schedule (PANAS)</td>
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<td></td>
</tr>
<tr>
<td>Positive affect</td>
<td>28.8 (6.6)</td>
<td>31.8 (5.5)</td>
<td>.100</td>
</tr>
<tr>
<td>Negative affect</td>
<td>11.4 (1.6)</td>
<td>10.8 (1.6)</td>
<td>.213</td>
</tr>
<tr>
<td>Depression Anxiety Stress Scales (DASS21)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Depression</td>
<td>8.75 (4.4)</td>
<td>2.9 (3.6)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Anxiety</td>
<td>7.3 (5.9)</td>
<td>3.3 (2.5)</td>
<td>.004</td>
</tr>
<tr>
<td>Stress</td>
<td>12.1 (8.6)</td>
<td>8.8 (4.5)</td>
<td>.006</td>
</tr>
</tbody>
</table>

* Significance level for two-tailed independent-samples t test.

b One older adult did not complete this measure and was thus excluded from the comparison.

Fig. 1. Schematic of experimental task. Shown are (A) the three target conditions, (B) the four cue conditions, and (C) the sequence of events for the ANT used in the present study adapted from Fan et al. (2002).
of $0.10 for each trial. The type of incentive was counterbalanced, with half of the blocks being associated with potential gains, and the remaining half being associated with potential losses. Participants were notified about the type of incentive before each block, and received a running balance at the end of each block. Incentive type (gain vs. loss) had no effect on any of the measures of interest, in either age group, so all analyses are collapsed across gain and loss incentive blocks.

2.4. Procedure

Participants were brought to a quiet room and seated in a comfortable chair in front of the computer monitor and keyboard. Task instructions were presented on the computer screen as well as expressed verbally by the investigator to the participant. These instructions specified that participants should respond as quickly and as accurately as possible to the direction of the central arrow (i.e., left or right) using the marked keys of the keyboard. Participants were told that they would be given a balance of $15.00 which would increase or decrease depending on task performance. After receiving the instructions, participants completed two practice blocks, which were followed by six experimental blocks. Between each block, participants were required to take a minimum break of 30 s, with this break being at least 60 s following the third experimental block. After the ANT, participants completed a battery of neuropsychological measures, including the MMSE. Participants were then fully debriefed regarding the nature of the experiment and received a cash payment consisting of compensation for time and the bonus earned from the ANT.

2.5. Behavioral data analysis

Separate three-way mixed-model ANOVAs were carried out for RT and accuracy according to the various attention networks. Responses that occurred after the 1700 ms response deadline or were incorrect were not included in analyses of RT. To assess alerting, contrasts of no and double cue conditions were of interest, so the ANOVAs included the factors age (young, old), cue (no, double), and target (congruent, incongruent, neutral). For orienting, contrasts of center and spatial cue conditions were relevant, so the ANOVAs included the factors age (young, old), cue (center, spatial), and target (congruent, incongruent, neutral). Lastly, executive control was assessed using ANOVAs that included the factors age (young, old), cue (center, spatial), and target (congruent, incongruent, neutral). Neutral targets were not included here since preliminary analyses showed no differences between responses to congruent and neutral targets (see also Fan et al., 2002). Network interactions (i.e., cue × target interactions) are not reported, since they are not relevant to the current hypotheses.

Following the procedure of Jennings et al. (2007), additional analyses were carried out on z-standardized RT to examine the potential influence of an age-related general slowing on network effects. To this end, we subtracted the mean RT for an individual participant for a given cue × target condition from his or her overall mean, and then divided this value by the participant’s overall standard deviation across all task conditions. This process was repeated for each condition and each participant. The resulting z-scores were analyzed following the same steps as those used for the non-adjusted RT.

2.6. ERP acquisition and data processing

Electrical brain activity was continuously digitized using ActiView (Bio-Semi; Wilmington, NC), with a band-pass filter of 208 Hz and a 1024 Hz sampling rate. Recordings made from FPz, F3, Fz, FCz, C3, Cz, C4, CPz, P3, Pz, P4, POz, O1, Oz, O2, M1, M2, CMS and DRL were stored for off-line analysis. Horizontal and vertical eye movements were also recorded using channels placed at the outer canthi and at inferior orbits, respectively. Data processing was conducted using BESA 5.3 Research (MEGIS; Gräfelfing, Germany). The contributions of both vertical and horizontal eye movements were reduced from the EEG record using the VEOG and HEOG artifact options in BESA following average referencing. Using a 0.1 (12 db/occ; zero phase) high-pass and 30 (24 db/occ; zero phase) Hz low-pass filter, epochs were defined relative to the onset of the context display and test display. Both cue and target epochs were baseline corrected according to a 200 ms pre-stimulus interval and neural activity was examined 1000 ms post-stimulus. Epochs were rejected on the basis of amplitude difference exceeding 100 μV, gradient between consecutive time points exceeding 75 μV, or, signal lower than 0.01 μV, within any channel.

2.7. ERP data analysis

At the time of the cue, posterior N1 and CNV were examined. We analyzed posterior N1 in a time window of 150–250 ms following the presentation of the cue, or in the case of the no cue condition, following the time at which a cue would have otherwise occurred. This component was averaged at parietal (P3, Pz, P4) and occipital (O1, Oz, O2) electrodes, respectively. Separate analyses of this component were carried out for alerting and orienting such that an age (young, old) × cue (no, double) × electrode site (parietal, occipital) ANOVA was used for alerting, and an age (young, old) × cue (center, spatial) × electrode site (parietal, occipital) ANOVA was used for orienting. Given the short cue-target duration of the ANT, CNV was not separated into early and late stages, but instead considered as a single component from 250 ms after cue-onset to the time of target onset (i.e. 500 ms post cue-onset). The same analyses of alerting and orienting used for posterior cue N1 were carried out for CNV, with the exception of electrode site, as this component was observed, and averaged, at FCz and Cz.

Regarding target analyses, posterior target P1 and N1 amplitudes were analyzed 100–150 ms and 150–250 ms following the presentation of target stimuli respectively. Much like for the posterior cue N1, these components were each averaged at parietal (P3, Pz, P4) and occipital electrodes (O1, Oz, O2). The ANOVAs performed were identical to those used for posterior cue N1, again with separate contrasts for alerting and orienting.

Fronto-central target N2 mean amplitude was examined 280–380 ms following the presentation of target stimuli at FCz, as this window centered on the mean peak latency of this component for both groups. Since this component was considered in relation to executive control, an age (young, old) × cue (no, double, center, spatial) × target (congruent, incongruent) ANOVA was used to contrast the effects of congruent and incongruent targets on fronto-central N2 amplitude. As in the behavioral analyses, neutral targets were not included due to the similarity between ERPs for neutral and congruent targets (Neuhaus, Urbanek, et al., 2010).

The last component of interest was the target P3. As with the frontal-central target N2 analysis, the aim here was to compare target responses related to the executive control network.

Both peak latency and amplitude were considered centro-parietally (Pz, CPz) and fronto-centrally (Cz, FCz) by averaging the values for the electrodes at each of these respective sites. Mean peak latencies were determined for each cue by target condition (with the exception of neutral targets) using a time window of 300–800 ms following target presentation. As visual inspection revealed a wider distribution of the P3 waveform in older adults, mean amplitudes were determined over a 200 ms window for older adults and a 100 ms window for younger adults. These time windows were centered at the mean peak latencies determined previously. For both peak latency and mean amplitude, separate
three-way ANOVAs of age (young, old) × cue (no, double, center, spatial) × target (congruent, incongruent) were used for centro-parietal target P3 and fronto-central target P3 respectively.

3. Results

3.1. Behavioral results

3.1.1. Accuracy

Means and standard errors obtained for the behavioral measures of interest are presented in Table 2 according to cue and target condition. When accuracy for no and double cue conditions was analyzed to examine effects of alerting, there was no main effect of cue, $F(1,46) = 2.00, p = .164, \eta^2_p = .04$, or age, $F(1,46) = 1.71, p = .198, \eta^2_p = .04$, nor an Age × Cue interaction, $F(1,46) = 1.70, p = .199, \eta^2_p = .04$. Comparisons of center and spatial cue conditions did not show an effect of age, $F(1,46) = 3.15, p = .083, \eta^2_p = .06$. Orienting did influence accuracy, as a main effect of cue, $F(1,46) = 10.60, p = .002, \eta^2_p = .19$, revealed that accuracy was significantly higher following spatial cues relative to center cues. This effect was similar for both younger and older adults, as no significant Age × Cue interaction was present, $F(1,46) = .018, p = .939, \eta^2_p < .01$. Accuracy also showed flanker interference effects. A significant effect of target was found when congruent and incongruent targets were compared, $F(1,46) = 2.45, p = .124, \eta^2_p = .05$, with higher accuracy for congruent targets than for incongruent targets. The main effect of age was not significant, $F(1,46) = 28.25, p = .002, \eta^2_p = .11$, nor was the interaction of Age × Target, $F(1,46) = 3.25, p = .078, \eta^2_p = .07$, though there was a trend toward a reduced flanker interference effect on accuracy for older adults relative to younger adults.

3.1.2. Reaction time

Analyses of alerting involving no and double cue conditions yielded a main effect of age, $F(1,46) = 75.52, p < .001, \eta^2_p = .62$, with younger adults responding significantly faster than older adults. Additionally, there was a main effect of cue, $F(1,46) = 215.29, p < .001, \eta^2_p = .82$, as well as a Cue × Age interaction, $F(1,46) = 6.19, p = .017, \eta^2_p = .12$. As this interaction shows, even though mean RT was shorter in the double cue compared to the no cue condition for both groups, this difference was larger for younger adults than for older adults.

The ANOVA used for orienting also showed main effects of age, $F(1,46) = 65.90, p < .001, \eta^2_p = .59$, and cue, $F(1,46) = 266.40, p < .001, \eta^2_p = .85$, as well as an interaction of Cue × Age, $F(1,46) = 10.52, p = .002, \eta^2_p = .19$. Again, RT was shorter for younger adults than for older adults. Spatial cues elicited faster responding than center cues, for both age groups, but the size of this effect was larger for older adults than for younger adults.

Comparisons of congruent and incongruent target conditions used to assess executive control yielded main effects of age, $F(1,46) = 63.70, p < .001, \eta^2_p = .58$, and cue, $F(1,46) = 187.76, p < .001, \eta^2_p = .58$, as well as a Target × Age interaction, $F(1,46) = 8.81, p = .005, \eta^2_p = .16$. Here too, younger adults exhibited shorter RT in comparison to older adults. Both age groups showed a typical flanker effect wherein incongruent targets were responded to slower than congruent targets. This effect was larger for older adults than for younger adults.

3.1.3. z-Transformed reaction time

After $z$-transforming each participant’s RTs, the Age × Cue interaction indicative of alerting remained significant, $F(1,46) = 17.38, p < .001, \eta^2_p = .27$, again with younger adults showing greater alerting than older adults. However, the Cue × Age interaction previously found for orienting was no longer significant, $F(1,46) = .96, p = .333, \eta^2_p = .02$. Additionally, the Target × Age interaction related to executive control also failed to reach significance, $F(1,46) = .41, p = .527, \eta^2_p = .01$. Younger adults and older adults thus did not differ in terms of orienting or executive control when controlling for age-related slowing.

3.2. Cue-related ERPs

ERPs wavesforms locked to cue onset are shown in Fig. 2 (posterior sites) and Fig. 3 (fronto-central sites). Target-locked ERP waveforms, averaged by cue condition at posterior sites, are shown in Fig. 4. Topographic maps of cue and target generated EEG activity for each of the cue conditions are presented in Fig. 5.

3.2.1. Posterior cue N1 amplitude

3.2.1.1. Alerting. The ANOVA involving no and double cue trials yielded a main effect of cue, $F(1,46) = 120.97, p < .001, \eta^2_p = .73$. As expected, posterior cue N1 mean amplitude was significantly more negative following double cues ($M = -.12 \mu V$) compared to when no cue was presented ($M = .29 \mu V$). There was also an effect of electrode site such that posterior cue N1 mean amplitude was more negative at occipital sites ($M = -.103 \mu V$) versus parietal sites ($M = -.40 \mu V$). Further, these effects interacted, $F(1,46) = 69.34, p < .001, \eta^2_p = .60$, with the effect of cue being larger at occipital sites ($M = -.264 \mu V$ versus $M = -.58 \mu V$) than parietal sites ($M = -.80 \mu V$ versus $M = .00 \mu V$). There was no effect of age, nor were any interactions involving age present.

3.2.1.2. Orienting. The ANOVA using center and spatial cue trials revealed an effect of cue, $F(1,46) = 10.64, p = .002, \eta^2_p = .19$, with the negativity of posterior cue N1 being greater for spatial cues ($M = -.293 \mu V$) than for center cues ($M = -.153 \mu V$). The Cue × Age interaction was significant, $F(1,46) = 10.23, p = .003, \eta^2_p = .18$. As Fig. 6 shows, the orienting effect was significant for older adults, $F(1,23) = 10.64, p < .001, \eta^2_p = .48$ ($M = -.63 \mu V$ versus
Fig. 2. Cue-locked ERP waveforms at posterior sites. ERP waveforms averaged by group (younger adults on top; older adults on bottom) are shown for each cue condition. Cue conditions associated with alerting are shown in black, i.e., no cue condition (dashed line) and double cue condition (solid line). Cue conditions associated with orienting are shown in gray, i.e., center cue condition (dashed line) and spatial cue condition (solid line). Cue onset occurs at 0 ms.

\[ M = 0.15 \text{ \mu V}, \text{ but not younger adults, } F(1,23) < .01, p = .964, \eta_p^2 < .01 (M = 0.15 \text{ \mu V versus } M = 0.16 \text{ \mu V}). \] Further, there was a Cue \times Electrode Site interaction, \( F(1,46) = 7.61, p = .008, \eta_p^2 = .14, \) with the difference in cue N1 amplitude for center and spatial cues being significant at occipital sites (\( M = 0.26 \text{ \mu V versus } M = 0.33 \text{ \mu V} \)), \( F(1,46) = 13.94, p = .001, \eta_p^2 = .23, \) but not at parietal sites (\( M = 0.05 \text{ \mu V versus } M = 0.15 \text{ \mu V} \)), \( F(1,46) = 2.65, p = .110, \eta_p^2 = .05. \)

3.2.2. Contingent negative variation (CNV) amplitude

3.2.2.1. Alerting. CNV for no and double cue conditions showed greater negativity at FCz (\( M = 1.00 \text{ \mu V} \)) than at Cz (\( M = 0.70 \text{ \mu V} \)), as there was a significant main effect of electrode site, \( F(1,46) = 6.30, p = .016, \eta_p^2 = .120. \) There was also a main effect of cue, \( F(1,46) = 12.01, p = .001, \eta_p^2 = .21, \) with CNV being more negative for the double cue condition (\( M = 1.29 \text{ \mu V} \)) than the no cue condition (\( M = 0.01 \text{ \mu V} \)). These effects of electrode site and cue interacted, \( F(1,46) = 15.02, p < .001, \eta_p^2 = .25, \) such that the amplitude difference for no and double cues was larger at FCz (\( M = 0.40 \text{ \mu V versus } M = 1.50 \text{ \mu V} \)) than at Cz (\( M = 0.03 \text{ \mu V versus } M = 0.98 \text{ \mu V} \)). CNV amplitude for no and double cues did not differ between younger and older adults, \( F(1,46) = 9.2, p = .342, \eta_p^2 = .02, \) nor did the effect of cue interact with age, \( F(1,46) = .832, p = .431, \eta_p^2 = .01. \)

3.2.2.2. Orienting. Similar to what was found for no and double cues, CNV amplitude for center and spatial cues was more negative at FCz (\( M = 1.68 \text{ \mu V} \)) than at Cz (\( M = 1.24 \text{ \mu V} \)), \( F(1,46) = 7.46, p = .009, \eta_p^2 = .139. \) There was an effect of cue, \( F(1,46) = 20.35, p < .001, \eta_p^2 = .307, \) such that spatial cues produced greater negativity (\( M = 1.76 \text{ \mu V} \)) than did center cues (\( M = 1.15 \text{ \mu V} \)). The difference between spatial and center cues was larger at FCz (\( M = 1.22 \text{ \mu V versus } M = 2.13 \text{ \mu V} \)) than it was at Cz (\( M = 1.09 \text{ \mu V versus } M = 1.39 \text{ \mu V} \)) as there was a significant Electrode Site \times Cue interaction, \( F(1,46) = 23.55, p < .001, \eta_p^2 = .339. \) Here too, CNV was unaffected by aging as there was no effect of age, \( F(1,46) = 1.41, p = .240, \eta_p^2 = .03, \) and no Cue \times Age interaction, \( F(1,46) = .01, p = .920, \eta_p^2 < .01. \)

3.2.2.3. Posterior target P1 amplitude

3.2.2.3.1. Alerting. The comparison of P1 amplitude for targets preceded by either no cue or a double cue yielded main effects of electrode site, \( F(1,46) = 5.95, p = .019, \eta_p^2 = .12, \) and cue, \( F(1,46) = 17.041, p < .001, \eta_p^2 = .27. \) P1 amplitude was more positive at occipital sites (\( M = 0.21 \text{ \mu V} \)) than at parietal sites (\( M = 0.19 \text{ \mu V} \)), as well as more positive in the no cue condition (\( M = 0.39 \text{ \mu V} \)) than the double cue condition (\( M = 0.36 \text{ \mu V} \)). These effects, however, interacted such that the difference in the no cue condition from the double cue condition was significant at parietal sites (\( M = 0.79 \text{ \mu V versus } M = 1.17 \text{ \mu V} \)), \( F(1,46) = 76.51, p < .001, \eta_p^2 = .63, \) but not at occipital sites (\( M = 0.01 \text{ \mu V versus } M = 0.44 \text{ \mu V} \)), \( F(1,46) = 2.90, p = .095, \eta_p^2 = .06. \) Further, there was an interaction of Electrode Site \times Age, \( F(1,46) = 5.135, p = .028, \)
with the component being more positive at occipital than parietal sites in younger adults ($M = 1.00 \mu V$ versus $M = -0.37 \mu V$), $F(1,23) = 21.99, p < .001, \eta^2_p = .49$, but not significantly different at the two locations in older adults ($M = .72 \mu V$ versus $M = .19 \mu V$), $F(1,23) = 3.71, p = .067, \eta^2_p = .14$.

3.2.4. Posterior target N1 amplitude

3.2.4.1. Alerting. There was a significant main effect of cue, $F(1,46) = 90.67, p < .001, \eta^2_p = .66$, as well as a significant Cue × Electrode Site interaction, $F(1,46) = 23.74, p < .001, \eta^2_p = .34$. With respect to the effect of cue, double cues ($M = 3.21 \mu V$) led to significantly more negative posterior target N1 amplitudes than did no cues ($M = -1.32 \mu V$). As suggested by the Cue × Electrode Site interaction, this alerting effect was larger at parietal ($M = -3.59 \mu V$ versus $M = -0.86 \mu V$) than occipital sites ($M = -2.82 \mu V$ versus $M = -1.78 \mu V$). No age differences were found.\(^{3}\)

3.2.4.2. Orienting. There was a significant main effect of cue, $F(1,46) = 75.63, p < .001, \eta^2_p = .62$, and interaction of Cue × Electrode Site, $F(1,46) = 8.70, p = .005, \eta^2_p = .16$. Posterior target N1 mean amplitudes were more negative following spatial cues ($M = -3.31 \mu V$) compared to center cues ($M = -1.75 \mu V$). In contrast to what was found for alerting, the orienting effect was larger at occipital sites ($M = -3.69 \mu V$ versus $M = -1.83 \mu V$) than at parietal sites ($M = -2.93 \mu V$ versus $M = -1.67 \mu V$). Age did not influence these effects.

3.3. Target-related ERPs

ERPs waves form at midline sites, averaged by target type, are presented in Fig. 6. Topographic maps of EEG activity generated following congruent and incongruent targets are shown in Fig. 7.

3.3.1. Fronto-central target N2 amplitude

The analysis of target N2 mean amplitude at FCz showed no main effect of age, $F(1,46) = 8.38, p = .365, \eta^2_p = .02$. There was, however, an effect of target, $F(1,46) = 10.70, p = .002, \eta^2_p = .19$, which interacted with age, $F(1,46) = 6.20, p = .016, \eta^2_p = .12$, such that fronto-central target N2 was larger for incongruent targets than congruent targets in younger adults ($M = -1.40 \mu V$ versus $M = -0.99 \mu V$), $F(1,23) = 10.22, p = .004, \eta^2_p = .31$, but not older adults ($M = -1.60 \mu V$ versus $M = -1.52 \mu V$), $F(1,23) = 1.09, p = .307, \eta^2_p = .05$.

3.3.2. Target P3 latency

At centro-parietal sites, target P3 peak latency occurred earlier for younger adults ($M = 464 \mu V$) than for older adults ($M = 577 \mu V$), as an effect of age was observed, $F(1,46) = 45.54, p < .001, \eta^2_p = .50$. There was also an effect of target, $F(1,46) = 11.50, p < .001, \eta^2_p = .20$, such that peak latency was longer for incongruent flankers ($M = 535 \mu V$) than for congruent flankers ($M = 505 \mu V$). These effects did not interact, $F(1,46) = 2.03, p = .161, \eta^2_p = .04$.

At fronto-central sites, there was an effect of age, $F(1,46) = 21.26, p < .001, \eta^2_p = .32$, and a Target × Age interaction, $F(1,46) = 4.41, p = .041, \eta^2_p = .09$.

\( ^{3} \) An exploratory age (young, old) × cue (no, double) × hemisphere (left [P3, O1], right [P4, O2]) mixed-model ANOVA was run to investigate potential hemispheric effects of alerting on target N1. This yielded a significant three-way interaction of Age × Cue × Hemisphere, $F(1,46) = 4.90, p = .004, \eta^2_p = .17$. In younger adults, the alerting effect on target N1 was significantly larger in the left hemisphere ($M = -3.79 \mu V$ versus $M = -1.31 \mu V$) compared to the right ($M = -3.00 \mu V$ versus $M = -1.16 \mu V$), $F(1,23) = 5.05, p = .035, \eta^2_p = .18$. The asymmetric alerting effect did not quite reach significance in older adults, $F(1,23) = 4.04, p = .056, \eta^2_p = .15$, despite a numerically larger effect in the right hemisphere ($M = -3.55 \mu V$ versus $M = -2.02 \mu V$) compared to the left ($M = -3.33 \mu V$ versus $M = -2.29 \mu V$). It is possible then that age differences in alerting may be related to differences in the lateralization of this network.
Again, peak latency occurred earlier for younger adults ($M = 569$ ms) than for older adults ($M = 666$ ms). Also, younger adults showed significantly earlier peak latency of P3 for congruent compared to incongruent targets ($M = 553$ ms versus $M = 585$ ms), $F(1,23) = 9.14$, $p = .006$, $\eta^2_p = .28$, while older adults did not show this difference ($M = 675$ ms versus $M = 658$ ms), $F(1,23) = .91$, $p = .350$, $\eta^2_p = .04$.

As an additional analysis to compare the topography of target P3, latency at the two locations were compared adding the factor of electrode site to the analysis, which resulted in a four-way mixed model ANOVA. An effect of electrode site, $F(1,46) = 81.98$, $p < .001$, $\eta^2_p = .64$, revealed that peak latency was significantly shorter at centro-parietal sites ($M = 520$ ms) compared to fronto-central sites ($M = 618$ ms), independent of age.

### 3.3.3. Target P3 amplitude

At centro-parietal sites, there was a main effect of target on P3, $F(1,46) = 25.63$, $p < .001$, $\eta^2_p = .36$, such that the amplitude of this component was reduced for incongruent targets ($M = 3.62 \mu V$) relative to congruent targets ($M = 4.44 \mu V$). As revealed by an interaction of Target $\times$ Age, $F(1,46) = 14.42$, $p < .001$, $\eta^2_p = .24$, though, this effect of target was significant for older adults ($M = 2.64 \mu V$ versus $M = 4.07 \mu V$), $F(1,23) = 40.47$, $p < .001$, $\eta^2_p = .64$, but not younger adults ($M = 4.60 \mu V$ versus $M = 4.80 \mu V$), $F(1,23) = .78$, $p = .387$, $\eta^2_p = .03$, despite no main effect of age, $F(1,46) = 2.80$, $p = .101$, $\eta^2_p = .06$.

A similar pattern was observed at fronto-central sites. Mean amplitude did not differ for younger and older adults, $F(1,46) = .04$, $p = .841$, $\eta^2_p < .01$, but again there was a Target $\times$ Age interaction, $F(1,46) = 8.86$, $p = .005$, $\eta^2_p = .16$, with target P3 amplitude being reduced for incongruent relative to congruent targets in older adults ($M = 1.31 \mu V$ versus $M = 2.12 \mu V$), $F(1,23) = .83$, $p = .373$, $\eta^2_p = .04$, but not younger adults ($M = 1.99 \mu V$ versus $M = 1.74 \mu V$), $F(1,23) = 12.77$, $p = .002$, $\eta^2_p = .36$. Age effects on P3 amplitude modulation are shown in Fig. 7.

As was the case for target P3 latency, the two electrode regions were compared in a four-way ANOVA that included the factor electrode site. Mean amplitude did not differ for younger and older adults, $F(1,46) = 31.34$, $p < .001$, $\eta^2_p = .41$, target P3 mean amplitude was shown to be more positive at centro-parietal sites ($M = 4.03 \mu V$) than at fronto-central sites ($M = 1.79 \mu V$) for both younger and older adults. Age differences for all of the described behavioral and ERP measures of alerting, orienting, and executive control are summarized in Table 3.
Fig. 5. Topographic voltage maps of EEG activity by cue condition following cue (top panel) and target (bottom panel) presentation.

Fig. 6. Target-locked ERP waveforms along the midline. ERP waveforms are shown for congruent (solid line) and incongruent (dashed line) target conditions by group. Target onset occurs at 0 ms.
4. Discussion

The aim of the present study was to evaluate age differences in selective attention at behavioral and neural levels. To do so, we administered the ANT to younger and older adults while electrophysiological data were recorded. Despite an overall slowing, older adults exhibited typical network effects of alerting, orienting, and executive control. Age differences were initially observed behaviorally on all of these networks, with an age-related enhancement of orienting, and decline of alerting and executive control. After correcting RT for age-related slowing effects though, the only age difference that remained significant was that for alerting, replicating the findings of Gamboz et al. (2010) and Jennings et al. (2007).

In many ways, the electrophysiological activity generated by older adults during the task matched that of younger adults; however, there were some distinct differences as discussed below.

In younger adults, the ERP results related to alerting and orienting parallel past findings in a number of ways. Previously, Neuhaus, Urbanek, et al. (2010) reported that at the time of the cue, posterior N1 amplitude was largest in the double cue condition, intermediate in the center and spatial cue conditions, and absent in the no cue condition. It was suggested that this component might simply reflect the properties of the stimulus, rather than meaningful attentional processes. Our results support this view of cue N1, at least for younger adults, as a similar pattern was observed. Further, in the present study, effects of alerting and orienting were exhibited on N1 amplitude at the time of the target, with the effect of alerting being largest at parietal sites, and orienting at occipital sites. This too replicates what Neuhaus, Urbanek, et al. (2010) and Galvao-Carmona et al. (2014) have reported previously. Effects of alerting and orienting on target P1 amplitude, however, diverged from Galvao-Carmona et al. (2014), as they found an orienting effect, but no alerting effect, whereas we report reversed effects of alerting and orienting. The difference might be explained by the fact that Galvao-Carmona et al. (2014) examined P1 at sites not observed in the present study (i.e., PO5 and PO6). What is worth noting, however, is that our findings echo a common finding in spatial orienting tasks in which invalid cues produce larger P1 amplitudes than valid spatial cues, evidencing a functional dissociation between P1 and N1 components (Doallo et al., 2004; McDonald et al., 1999). Lastly, CNV amplitude showed effects of alerting and orienting in the present study. Galvao-Carmona et al. (2014) too report effects of these networks on CNV, though they indicate that alerting only influences the late stage of CNV. Due to the short interval of CNV in the present study, observations based on the two stages are not possible.

The pattern of results for alerting and orienting in older adults mirrored that of younger adults with the exception of one notable difference. At the time of the cue, older adults showed an effect of orienting on N1 amplitude at occipital sites. This finding suggests that older adults in the spatial cue condition generated activity over and above what would be expected from the cue’s properties alone, possibly reflecting stronger engagement with spatial cues compared to younger adults. Despite this enhanced cue effect though, the behavioral orienting enhancement in older adults was eliminated when RT was adjusted to account for age-related slowing.

Perhaps also noteworthy are the lack of age differences on target P1 and CNV, especially in relation to orienting. Using a spatial cueing task, Curran et al. (2001) found that younger adults showed similar P1 amplitudes in response to validly and invalidly cued targets, whereas older adults showed larger amplitudes for invalidly
cued targets. However, the lack of an age difference here is somewhat unsurprising given the number of studies that have observed a reversal of the P1 validity effect in younger adults, as described above. With respect to CNV, this component has been shown to be greater in response to spatial cues in older adults relative to younger adults (Hong et al., 2015). However, the results of the current study may not be comparable in this regard given the short interval of CNV.

What seems most surprising, however, is a failure to detect age differences in alerting in the ERP components of interest, given the presence of a behavioral difference, both before and after adjusting RT for age-related slowing. We speculate that this mismatch may result from interactions between the alerting and executive control networks. Specifically, a common behavioral finding in the ANT is that double cues (relative to no cues) shorten response times to incongruent targets, but do not necessarily increase accuracy (Fan et al., 2002; Gamboz et al., 2010; Jennings et al., 2007). This has important implications with respect to age differences, given that older adults more often prioritize accuracy, whereas younger adults prioritize speed (Forstmann et al., 2011; Starns & Ratcliff, 2010). Older adults may thus lose the initial speed benefit of the double cue as they work to maintain accuracy in the incongruent target condition, thereby reducing their overall alerting effect. The increased alerting effect present in older adults then may be greater in response to spatial cues in older adults relative to younger adults, likely indicative of the overcentralization of attention in older adults (e.g. Galvao-Carmona et al., 2014; Neuhaus, Urbanek, et al., 2010; Potts, 2011). This discrepancy may be attributable to a subtle difference in target presentation between the flanker task and the ANT. In most flanker tasks, targets are consistently presented in a central location, whereas in the ANT targets are presented both above and below a central fixation. Since the location of the target is less predictable in the ANT, older adults may not have been able to process targets centrally, as previously suggested, resulting in larger N2 amplitudes than typically found. Further, P3 was delayed in older adults relative to younger adults, likely indicative of the overall slowing shown by older adults. The latency of this component was sensitive to target congruency in older adults, though, only at centro-parietal sites, whereas this effect extended to fronto-central sites in younger adults. In contrast to what was found for

Table 3
Summary of age differences on behavioral and ERP attention network effects.

<table>
<thead>
<tr>
<th>Network effect</th>
<th>Age-related decrease</th>
<th>No age difference</th>
<th>Age-related increase</th>
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<td>Alerting</td>
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<td>Target-P3 amplitude</td>
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<td>Orienting</td>
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<td>Target-P3 latency (FC)</td>
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<td>Target-P3 amplitude (CP)</td>
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a Effect absent in younger adults.
b Effect absent in older adults; CP = centro-parietal; FC = fronto-central.
c Executive control is measured as interference cost (smaller cost means greater control).

differences as a result of target congruency. However, greater amplitudes of N2 under incongruent target conditions during flanker tasks have been reported elsewhere (e.g. Clayson & Larson, 2011; Grützmann et al., 2014; Purmann et al., 2011). The lack of this effect in the study by Neuhaus et al. (2007) may be reflective of the small sample size (n = 16), as offered by the authors. P3 latency was also affected by target congruency. Although neither Neuhaus, Urbanek, et al. (2010) nor Galvao-Carmona et al. (2014) reported on the latency of this component, Neuhaus et al. (2007) did observe this effect in control participants. Somewhat unexpectedly, P3 amplitude was not influenced by target congruency in the present study. This is counter to previous observations as the amplitude of this component tends to be decreased by incongruent target conditions (e.g. Galvao-Carmona et al., 2014; Neuhaus et al., 2007; Neuhaus, Urbanek, et al., 2010; Potts, 2011).

N2 and P3 modulation on the basis of target congruency in older adults was distinct from that of younger adults. Unlike younger adults, fronto-central N2 amplitude was not affected by target congruency. This age difference is common in flanker studies involving younger and adults (e.g. Hsieh & Fang, 2012; Hsieh et al., 2012; Wild-Wall et al., 2008), however, unlike previous studies that report N2 to be absent in older adults, the overall amplitude of this component did not differ between the two groups in the current study. This discrepancy may be attributable to a subtle difference in target presentation between the flanker task and the ANT. In most flanker tasks, targets are consistently presented in a central location, whereas in the ANT targets are presented both above and below a central fixation. Since the location of the target is less predictable in the ANT, older adults may not have been able to process targets centrally, as previously suggested, resulting in larger N2 amplitudes than typically found. Further, P3 was delayed in older adults relative to younger adults, likely indicative of the overall slowing shown by older adults. The latency of this component was sensitive to target congruency in older adults, though, only at centro-parietal sites, whereas this effect extended to fronto-central sites in younger adults. In contrast to what was found for
younger adults, P3 amplitude was reduced by incongruent targets in older adults. Previous work has shown a greater effect of target congruency on P3 amplitude in older adults (e.g. Wild-Wall et al., 2008), but again the complete absence of such an effect in younger adults seems to be unique to the current study. As P3 was largest at centro-parietal sites for both younger and older adults, it appears as though this component was not shifted anteriorly in older adults as is sometimes reported during executive control tasks (e.g., Alperin et al., 2014; O’Connell et al., 2012). Though, it should be noted that at fronto-central sites older adults continued to show a reduction in P3 amplitude for incongruent targets, which provides partial support for a more anterior distribution of executive control processes in older adults.

When all of the ERP results are taken together, it can be argued that the early visual processes involved in selective attention, as well as those used to maintain warning and orienting signals, remain largely similar to those of younger adults with healthy aging. At the time of response, however, there seems to be some divergence between younger and older adults with regards to identifying and resolving conflict. In order to interpret these findings, it is useful to further characterize the executive control network as involving both proactive and reactive mechanisms (Braver, 2012; Braver & Barch, 2006). Proactive mechanisms work to maintain goal-relevant information, biasing attention so as to optimally respond to task demands. In contrast, reactive mechanisms are activated when interference is detected to successfully resolve conflict. Our current findings suggest that proactive mechanisms are engaged similarly by younger and older adults, as the two groups respond similarly to cues that can be used to increase task performance (cue N1), maintain this information in comparable ways (CNV), and show enhanced attention to the target in the informative cue conditions (target N1). However, as target congruency cannot be anticipated in advance, reactive control mechanisms have to be activated at the time of the target, especially in the incongruent condition where more resources are required. Reactive control seems to differ between the two groups as the ERP components involved in conflict detection and resolution (N2 and P3) are where age differences are found.

As noted earlier, younger and older adults differentially emphasize speed and accuracy goals (Forstmann et al., 2011; Starns & Ratcliff, 2010). Differences in the reactive control mechanisms engaged by the two groups then may reflect these distinct strategies. Younger adults, for example, seem to attempt to resolve conflict as quickly as possible, differentiating between congruent and incongruent stimuli as early as the time of N2. Older adults, in contrast, recruit the same amount of resources to evaluate target stimuli regardless of congruency, as evidenced by N2 amplitude. At the time of P3, younger adults seem to have already determined a response, and take no additional effort to adjust, as the amplitude of this component is not modulated by congruency in this group. Older adults, on the other hand, do show modulation of this component on the basis of congruency, and thus appear to exert greater effort to inhibit distracting flankers and select the correct response, favoring accuracy rather than speed. This is partially supported by a trend toward less of an interference effect on accuracy in older adults relative to younger adults. Such an interpretation does not necessarily indicate reactive control mechanisms are deficient in older adults, but rather may be engaged asymmetrically to achieve different goals.

Despite our best efforts to include a wide range of older adults, the mean age for this group (65.1 years) is considered to be in the “young-old” range. As previous work has shown, the cortical thickness of structures involved in alerting and executive control is correlated with the efficiency of these networks, and age-related regional changes in cortical thickness could differentially affect alerting and executive control (Westlye, Grydeland, Walhovd, & Fjell, 2011). An important goal of future work, therefore, will be to examine whether the findings of the present study generalize to “old-old” cohorts, ideally using longitudinal approaches. Additionally, future studies should work to correlate the electrophysiological and behavioral markers of the ANT to further elucidate the relationship between the two measures. Another potential limitation of the current study is the use of the MMSE to screen for dementia-related cognitive impairment. Other screening tools exist that may be more suitable to differentiate healthy aging from pathological aging. Evidence exists to suggest, for example, that the Montreal Cognitive Assessment (MoCa; Nasreddine et al., 2005) has greater sensitivity in detecting mild cognitive impairment (MCI) than the MMSE – even when a cut-off score of 27, instead of 26, is used in the MMSE (Lerner, 2012; Luis, Keegan, & Mullan, 2009). Lastly, as with most cross-sectional research, age differences cannot be separated from cohort differences in the current study.

Despite these caveats, the current study contributes significantly to our understanding of the neural bases of attentional networks in healthy older adults. Unlike previous behavioral studies employing the ANT, we have demonstrated that age differences in attentional processes are not just a matter of discrepancies in the size of network effects brought on by differences in the timing of underlying processes, but instead represent distinct patterns of neural activity and recruitment. In establishing an understanding of typical patterns of electrophysiological activity during the ANT in healthy older adults, we hope that in the future such an understanding will be useful in identifying pathological forms of aging. It has been reported, for example, that patients with Alzheimer’s disease (AD) are more greatly affected by incongruent targets in the ANT than are healthy older adults (Fernandez-Duque & Black, 2006). Elsewhere, AD patients have been found to have an increased orienting effect when comparing responses following valid spatial cues to non-valid spatial cues, and may not show an alerting effect, though this is not always found (Festa-Martino, Ott, & Heindel, 2004; Tales, Snowden, Brown, & Wilcock, 2006). As selective attention processes seem to differ between healthy older adults and AD patients, it may be the case that so too do the electrophysiological markers generated by this population during the ANT, which may aid in diagnostic procedures. In line with this thinking, Stothart, Kazanina, Näätänen, Haworth, and Tales (2015) recently found AD patients and MCI patients to show reduced posterior target N1 amplitudes during a selective attention task.

5. Conclusion

The current study is the first to compare age differences in both behavioral and ERP markers of the ANT. After adjusting RT, younger and older adults differed behaviorally in alerting, but not orienting or executive control. However, the ERP markers of alerting showed similar modulation in both groups. This data suggests that behavioral age-deficits reported for alerting in the current study, as well as in previous studies, might be artificial. Instead, the behavioral effect may reflect an age-difference in the interaction between alerting and executive control brought on by the task’s demands, rather than an underlying alerting deficit, though further evidence is required to support this conclusion. Further, the lack of behavioral differences in executive control between younger and older adults reported here and elsewhere seems to mask complex differences in the underlying processes used to detect and resolve conflict between the two groups. Notably, younger and older adults show distinct differences in their engagement of reactive control mechanisms involved in executive control, despite equivalent behavioral effects when age-related
The effects of aging on attention.

Acknowledgments

This research was supported by the Natural Sciences and Engineering Research Council (DGC 358797 to J.S.), the Canada Research Chair program (J.S.), and an Early Researcher Award from the Ontario Ministry of Research and Innovation (J.S.). We thank Kathleen M. Lyons for assistance with data collection and Carson Pun for technical support.

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