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

Ryan S. Williams, Anna Lena Biel[1], Pete Wegier, Leann K. Lapp, Benjamin J. Dyson[2], Julia Spaniol*

Ryerson University, 350 Victoria St, Toronto, ON M5B 2K3, Canada

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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 temporo-parietal 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,

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* Corresponding author.
E-mail address: jspaniol@psych.ryerson.ca (J. Spaniol).

[1] Present address: Ludwig-Maximilians-Universität, Professor-Huber Square 2, 80539 Munich, Germany.

[2] Present address: University of Sussex, Brighton BN1 9RH, United Kingdom.

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& Quigley, 2015), including healthy older adults. Behavioral findings have consistently shown that the efficiency of the orienting network is uncompromised by aging, as older adults are able to use spatial cueing information as effectively as younger adults (Fernandez-Duque & Black, 2006; Gamboz, Zamarian, & Cavallero, 2010; Jennings, Dagenbach, Engle, & Funke, 2007). Observations of age differences in the 2 remaining networks, however, have been less consistent. For example, some behavioral studies have shown an age-related decline in alerting that was present even when RTs were corrected for age-related slowing (Gamboz et al., 2010; Jennings et al., 2007). In contrast, at least one other study (Fernandez-Duque & Black, 2006) reported age-related enhancement of this network, even though RT was not adjusted here. With respect to executive control, there have been reports of age-related decline within older adult populations (Mahoney, Verghese, Goldin, Lipton, & Holtzer, 2010), as well as between younger and older adults when RT was uncorrected, but no difference when RT is adjusted for slowing (Gamboz et al., 2010; Jennings et al., 2007; but see Fernandez-Duque & Black, 2006).

These inconsistent behavioral findings regarding age differences in the ANT may be partially accounted for by the number of trials used (i.e., 2–3 blocks of 96 trials) in such studies. As has been shown for both younger adults (Ishigami & Klein, 2010) and older adults (Ishigami & Klein, 2011), the reliability of the size of attention network effects derived from the ANT is improved when large data sets are used compared to smaller ones. Therefore, by relying on just a few blocks of the task, previous studies may not have been comparing network effects that accurately represent the two populations. Even with a large number of observations, however, age differences in selective attention are difficult to characterize with behavioral data alone. For example, it cannot readily be assessed whether the observed differences in attention networks are attributable to differences in the timing of underlying neural processes, or if such differences represent qualitatively different attentional processes or strategies engaged by younger and older adults. Converging methods may thus be necessary to elucidate age differences in attention networks.

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; Bareš & 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).

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, & Kakigi, 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, Hohnsbein, & Hoormann, 1994; Verleger, Jaśkowski, & 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 themselves, 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