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Age-related changes in the attentional control of visual cortex: A selective problem in the left visual hemifield

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ABSTRACT

To what extent does our visual-spatial attention change with age? In this regard, it has been previously reported that relative to young controls, seniors show delays in attention-related sensory facilitation. Given this finding, our study was designed to examine two key questions regarding age-related changes in the effect of spatial attention on sensory-evoked responses in visual cortex––are there visual field differences in the age-related impairments in sensory processing, and do these impairments co-occur with changes in the executive control signals associated with visual spatial orienting? Therefore, our study examined both attentional control and attentional facilitation in seniors (aged 66–74 years) and young adults (aged 18–25 years) using a canonical spatial orienting task. Participants responded to attended and unattended peripheral targets while we recorded event-related potentials (ERPs) to both targets and attention-directing spatial cues. We found that not only were sensory-evoked responses delayed in seniors specifically for unattended events in the left visual field as measured via latency shifts in the lateral occipital P1 elicited by visual targets, but seniors also showed amplitude reductions in the anterior directing attentional negativity (ADAN) component elicited by cues directing attention to the left visual field. At the same time, seniors also had significantly higher error rates for targets presented in the left vs. right visual field. Taken together, our data thus converge on the conclusion that age-related changes in visual spatial attention involve both sensory-level and executive attentional control processes, and that these effects appear to be strongly associated with the left visual field.

1. Introduction

Age-related changes in visual-spatial attention have been well documented (e.g., Kok, 2000; Lincourt, Folk, & Hoyer, 1997), with seniors showing marked deficits in the ability to modulate visual sensory processing in a top-down manner (Curran, Hills, Patterson, & Strauss, 2001). However, the extent of these deficits remains unclear. In particular, if seniors have sensory-related impairments in visual-spatial attention, are these problems at a purely sensory level in visual cortex, or might they co-occur with impairments in the volitional orienting of attention at an executive, control level? This possibility is not unfounded, as a general degradation of executive cognitive functioning is one of the hallmarks of the human aging process (e.g., Flicker, Ferris, & Reisberg, 1993; Gazzaley & D'Esposito, 2007; Koss et al., 1991; Nettelbeck & Rabbitt, 1992) and attentional control processes in prefrontal cortex are also known to decline with age (e.g., West & Schwarb, 2006). Given these issues, we wanted to address two specific questions regarding age-related changes in visual-spatial attention.

First, if seniors show impairments in the effect of visual spatial attention on sensory processing in visual cortex, are there visual field asymmetries in these impairments? The question arises because aging has been specifically associated with a greater rate of decline in cognitive functions localized in the right cerebral hemisphere relative to the left (e.g., Cherry, Adamson, Duclos, & Hellige, 2005; Lux, Marshall, & Thimm, 2008). With respect to visual spatial attention, the neurocognitive processes associated with spatial orienting also show strong laterality effects, such as is manifest in the strong prevalence of left visual neglect following damage to the right cerebral hemisphere (e.g., Bublak, Redel, & Finke, 2006; Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990), and the ability of the right hemisphere to orient attention to both visual hemifields but the left hemisphere only to the right visual field (e.g., Mangun et al., 1994). Nevertheless, previous studies examining differences in visual-spatial attention with age have collapsed data across visual field (e.g., Curran et al., 2001; Lorenzo-Lopez et al., 2002), thus leaving open the question of whether there may be age-related visual asymmetries in visual-spatial orienting.

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Second, to what extent are the reported age-related deficits in the effect of visual attention on sensory-level processing preceded by complimentary deficits in the control of visual-spatial orienting itself? In other words, given that executive control signals are the necessary antecedents to attention-related changes in visual sensory responses (e.g., Corbetta & Shulman, 2002; Green & McDonald, 2008; Hopfinger, Buonocore, & Mangun, 2000), are seniors showing problems relative to young adults only at a visual sensory level (e.g., Curran et al., 2001), or might these problems in visual cortex co-occur with deficits in executive control of visual-spatial attention as well?

To address these questions we had both young (under 30 years of age) and senior (over 65 years of age) participants perform a canonical spatial orienting task (Posner, 1980) while we recorded their brains electrical responses via event-related potentials (ERPs). For each trial participants maintained central fixation as a cue was presented centrally that predicted the visual field location (left or right upper quadrant) of a pending target that required a simple manual response indicating which side of fixation it was presented on. In this paradigm, we assessed the neurocognitive processes underlying the control of attentional orienting by examining the ERP responses to the attention-directing cues, with data analysis focusing on two components of interest, the early directing attentional negativity (EDAN) and the anterior directing attentional negativity (ADAN). Both of these components are assessed by comparing scalp electrode locations ipsilateral vs. contralateral to the visual field indicated by the visual cue; electrode sites contralateral to the cued hemifield are expected to yield more negative ERP amplitudes relative to the mirror ipsilateral sites (e.g., Green & McDonald, 2006; Jongen, Smulders, & Van der Heiden, 2007; Seiss, Gherri, Eardley, & Eimer, 2007). In terms of what the components capture functionally, the EDAN is thought to reflect the evaluation and interpretation of an attention-directing cue (e.g., Jongen et al., 2007) and is widely distributed over the scalp typically around 280–320 milliseconds (ms) post-cue (e.g., Jongen et al., 2007; Seiss et al., 2007; Talsma, Slagter, Nieuwenhuis, Hage, & Kok, 2005; Van Velzen & Eimer, 2003). In contrast, the ADAN is believed to reflect the act of actually orienting attention itself to the cued location and is localized to frontal-central lateral sites at approximately 350–400 ms post-cue (e.g., Jongen et al., 2007; Seiss et al., 2007; Talsma et al., 2005; Van Velzen & Eimer, 2003).

In turn, we assessed the facilitatory effects of attention on sensory/perceptual processing by comparing ERP responses to visual targets as a function of whether they were in an attended (or cued) vs. unattended (or uncued) location. In particular, the sensory-level effects of visual spatial attention are typically measured via two main ERP components, the lateral occipital P1 and N1 components. The P1 typically peaks around 100 ms post-stimulus and is believed to reflect the magnitude of the initial sensory-evoked response in visual cortex, likely in the V3/V4 region (e.g., Heinze et al., 1994; Woldorff et al., 1997), whereas the N1 typically peaks around 170–200 ms post-stimulus and has been tied to the initial perceptual/discriminative analysis of visual events (e.g., Vogel & Luck, 2000). For both components, the amplitude scales with the amount of attention oriented to the visual field location of the ERP-eliciting stimulus (e.g., Handy & Mangun, 2000; Luck et al., 1994; Mangun & Hillyard, 1991). At issue here was whether these effects of attention on P1 and N1 amplitude would change with age, and in particular, whether there would be any visual field asymmetries in these age-related effects.

2. Methods

2.1. Participants

Fourteen community-dwelling seniors, aged 66–74 years ($M = 69.3$, $SD = 2.67$; all female) and fourteen undergraduates, aged 18–25 years ($M = 20.86$, $SD = 1.96$; 10 female) participated. For the senior group, 14% had not received a high school diploma, 36% had a high school diploma, 36% had a trades certificate or equivalent, and 14% had a university degree. All senior participants were cognitively intact, as indicated by Mini-Mental Status Examination (MMSE) scores above 26 (Folstein, Folstein, & McHugh, 1975) ($M = 28.71$, $SD = 0.99$). One undergraduate participant was left-handed and all participants had normal or corrected-to-normal vision. All participants provided written informed consent and the reported research was approved by the Clinical Research Ethics Board (CREB) at the University of British Columbia.

2.2. Apparatus and stimuli

Trial sequence and timing are provided in Fig. 1. Stimuli were presented on an 18 in. colour monitor placed 100 cm from the subject. Cues were $1.26^\circ \times 0.46^\circ$, presented at fixation, cueing either the left or the right target location. Targets, which were $0.92^\circ \times 0.92^\circ$, appeared either in the left visual field or the right visual field (target was 4.57° from the top of the screen, 11.31° from the bottom of the screen, and 4.86° from the left/right edge of the screen) and remained on the screen until a response was made. The cue predicted target location with 80% accuracy. After a response was made, the next trial began immediately.

2.3. Procedure

The task required participants to indicate via button presses whether the target appeared in the right visual field or left visual field, as quickly and accurately as possible. Participants were instructed to press one button with their left hand if the target appeared on the left, and another button with their right hand if the target appeared on the right. There were 12 blocks all together, each with 76 trials (60 cued, 12 uncued, 4 catch). Each block lasted approximately 4 min. Participants were instructed to keep their eyes on the central fixation point for the duration of the experiment.

2.4. Electrophysiological recording and analysis

During task performance, electroencephalograms (EEGs) were recorded from 32 active electrodes (Bio-Semi Active 2 system) evenly distributed over the head. All EEG activity was recorded relative to two scalp electrodes located over medial-frontal cortex (CMS/DRL), using a second order low pass filter of 0.05 Hz, with a gain of 0.5 and digitized on-line at a sampling rate of 256 samples-per-second. To ensure proper eye fixation and allow for the correction and/or removal of events associated with eye movement artifacts, vertical and horizontal electro-oculograms (EOGs) were also recorded, the vertical EOG from an electrode inferior to the right eye, and the horizontal EOG from an electrode on the right outer canthus. Off-line, computerized artifact rejection was used to eliminate trials during which detectable eye movements ($>1^0$), blinks, muscle potentials, or amplifier blocking occurred. After artifact rejection, an average of 655 attended and 136 unattended trials were included in the analysis for each participant.

Statistical quantification of ERP data was based on mean amplitude measures relative to a −200 to 0 pre-stimulus baseline. Repeated-measures mixed-model ANOVAs were used, which had unpooled error terms in order to account for potential violations of sphericity for factors having more than 2 levels, a conservative approach that also controls for family-wise error rates (see Handy, Nagamatsu, Mickelborough, & Liu-Ambrose, 2009). Electrophysiological analysis was performed using ERPSS (UCSD; http://sdepl.ucsd.edu/erpss/doc/index.html), with electrode sites for analysis chosen based on previous research on these well-studied components (see below). In addition, because differences in latencies between young adults and seniors have been reported (e.g., Curran et al., 2001; Gilmore, 1995) amplitude analyses used latencies individually chosen based on group, according to the peak latency for seniors and young adults separately in each groups' grand averaged waveforms.

3. Results

3.1. Behaviour

Reaction times (RTs) and accuracy were recorded during the experiment and results are presented in Table 1 as a function of group (senior vs. young) and trial type. Behavioural data was analyzed in a mixed-model repeated measure ANOVA using SPSS (Version 16 for MAC) with group (seniors vs. young) as a between-subjects factor, and attention (cued vs. uncued) and visual field (right vs. left) as within-subjects factors. For RTs, participants were faster to respond to attended targets compared to unattended targets. This pattern was confirmed via a main effect of attention, $F(1,26) = 31.55$, $p < 0.001$. There was also a significant attention × visual field interaction, $F(1,26) = 8.48$, $p < 0.01$. Specif-