Age-related decline in attentional shifting: Evidence from ERPs

Giorgia Cona\textsuperscript{a,}*, Patrizia S. Bisiacchi\textsuperscript{a}, Piero Amodio\textsuperscript{b}, Sami Schiff\textsuperscript{b}

\textsuperscript{a} Department of General Psychology, University of Padua, Via Venezia, 8, 35131 Padua, Italy
\textsuperscript{b} Department of Medicine, University of Padua, Via Giustiniani, 2, 35128 Padua, Italy

**HIGHLIGHTS**

- The N2 and P3a for target stimuli were increased in old adults.
- The N2 and P3a for the stimulus following the target one were reduced in old adults.
- Aging is associated with a decline in shifting attention.
- These age-related changes might explain the increased attentional blink in elderly.

**ARTICLE INFO**

Article history:
Received 17 August 2013
Received in revised form 30 September 2013
Accepted 3 October 2013

Keywords:
Aging
ERPs
P3a
N2
Attentional shifting
Attention

**ABSTRACT**

The present study investigated age-related attentional changes by comparing event-related potentials (ERPs) in young and older adults during a rapid serial visual presentation task. We focused on analyzing the P3a and the N2 in both the target stimulus and the immediately succeeding irrelevant stimulus. As compared with younger adults, older adults exhibited a marked reduction in the amplitude of the P3a and N2 elicited by the stimulus following the target stimulus. Moreover, in younger adults, the P3a and N2 amplitudes did not differ between both stimuli, whereas in older adults these ERP components were significantly reduced in the subsequent stimulus compared to the target one. The age-related attenuation of P3a and N2 amplitudes for the subsequent stimulus indicates that older adults take longer and have more difficulty shifting their attention from one stimulus to the next one.

© 2013 Elsevier Ireland Ltd. All rights reserved.

1. Introduction

Aging has been associated with a decline in several cognitive functions, including attentional processing (e.g., [1,2]). Older adults perform worse than younger adults in selective attention tasks, which require focusing on a target stimulus while ignoring irrelevant stimuli [3] and in visual search paradigms [4]. Researchers have ascribed such findings to age-related decrease in processing speed [5], attentional capacity [6,7], or ability to inhibit irrelevant information [8,9]. Recently, others proposed that age-related decline in attention tasks might be due to older adults' slowness in shifting attention from one stimulus to the next (e.g., [10,11]).

Two major event-related potential (ERP) components were classically studied in relation to visual nonspatial attention. One is a positive wave peaking between 300 and 600 ms post-stimulus (P3a) over frontal regions. The other is a negative wave peaking between 200 and 400 ms post-stimulus (N2) over central sites [2,12,13]. The P3a reflects processes of attentional orientation and allocation [12,14,15]. The N2 encompasses multiple early negative subcomponents, which all occur roughly at 200 ms post-stimulus but reflect different cognitive processes and have different scalp distributions [16]. In the present study, we specifically refer to the N2b, which has been linked to detection and monitoring processes [17,18], to cognitive control [16], and attention switching [15]. As such, both N2 and P3a components are considered markers of attentional and monitoring resources [19,20] so they might help to identify which attentional mechanisms aging most affects.

These ERPs were typically measured as locked to relevant—target—stimuli, but how does aging influence the components elicited by the stimulus just following a target one? The analysis of such ERPs would let researchers evaluate whether older adults can rapidly shift attention from one stimulus to the following one. Yet this question is still unanswered. The few studies that took into account age-related changes in the “trial after” focused only on behavioral performance and used the rapid serial visual presentation (RSVP) task. RSVP involves

\* Corresponding author. Tel.: +39 0498276248.
E-mail addresses: giorgia.cona@unipd.it (G. Cona), patrizia.bisiacchi@unipd.it (P.S. Bisiacchi), piero.amodio@unipd.it (P. Amodio), sami.schiff@unipd.it (S. Schiff).
the serial presentation of visual stimuli in the same location and in rapid succession. These studies reported that both older and younger individuals have trouble identifying the second of two stimuli in close temporal proximity [21]. This phenomenon, the “attentional blink,” was more pronounced in older adults [21,23,24]. These studies proposed that a longer, more pronounced attentional blink in older adults might reflect their reduced ability to inhibit the distracter stimuli occurring between the target stimuli.

To our knowledge, only one study explored the effect of aging on ERPs elicited by the stimulus presented after the target stimulus [24]. This study used a complex RSVP paradigm and found that, unlike younger adults, older adults did not show the P3a for the stimulus following the target stimulus. This result suggested that older adults took longer to shift attention from the target stimulus to the following, irrelevant one, and they were not able to promptly allocate attention to this second stimulus. Nevertheless, the RSVP paradigm was comprised of a selective attention task and a go/no-go task, so it was not easy to fully tease apart the contribution of attentional processes and updating/inhibitory processes to the ERPs.

In the present study, we investigated more deeply the effects of aging on the P3a and N2 elicited by both the target and following stimulus, and focused specifically on selective attention task.

We made different predictions about the age effects on these ERPs based on the cognitive processes that might be affected by aging. If older individuals have a reduced capacity pool of attentional resources [6], we would expect a decrease in P3a and N2 amplitudes in both stimuli. If older adults have difficulty inhibiting irrelevant information [8], we would expect an enhancement in the amplitude of P3a and N2 elicited by the following stimulus, which was always irrelevant to the task. Finally, if older adults take longer to process stimuli and have difficulty shifting attention between them [11], we should hypothesize a reduction in P3a and N2 amplitudes particularly for the stimulus that follows the target one.

2. Materials and methods

The procedure has been described in detail elsewhere [25]; hence, only essential information is provided below.

Eighteen younger adults (mean ± SD; age: 26 ± 4 years; 8 females; education level: 16 ± 2 years) and 18 healthy older adults (age: 67 ± 6 years; 8 females; education level: 13 ± 5 years) took part in the study after giving signed informed consent. Part of sample data was taken from Cona et al. study [25]. The Hospital of Padua Ethical Committee approved the study.

The task was based on the first part of the Inhibitory Control Task (ICT) originally used by Amadio et al. [26]. Black letters appeared, one after another, for 500 ms without inter-stimulus interval, on the center of a white background computer screen. We instructed participants to press the computer spacebar only when the target letters “X” and “Y” appeared. The task was composed of 500 letters, 75 of which were target letters. Two target letters never appeared consecutively. We analyzed accuracy (% of correct responses) and mean reaction times (RTs) by two separate repeated-measures analyses of variance (ANOVA) with age (younger versus older adults) as the between-subjects factor.

We recorded EEG continuously with 29 Ag/AgCl scalp electrodes. The ground was Fpz and the reference was the linked mastoids. Vertical and horizontal eye movements were recorded. The EEG signal was filtered with a 30 Hz low-pass filter and down-sampled offline at 256 Hz. Epochs were locked to the onset of the target letters and included 500 ms of pre-stimulus and 1500 ms post-stimulus activity. Artifact correction was made using the Independent Component Analysis. The data was re-referenced to an average reference. Epoch rejection was performed with a cut-off of ±75 μV. Only epochs without errors were analyzed.

The ERP analysis focused on the P3a and N2 elicited both by the target letter (labeled first-P3a and first-N2, respectively) and by the letter just following it (labeled second-P3a and second-N2). We investigated age-related differences on the peak amplitude of the P3a waves over the lateral frontal regions with a $2 \times 2 \times 2$ ANOVA with electrode site (F7 versus F8), type of P3a (first versus second) as within-subjects factors, and age group (younger versus older adults) as the between-subjects factor. Since epochs were locked to the onset of target letters, the time interval was 180–500 ms after the target letter for the detection of the peak amplitude of the first-P3a and 700–1100 ms after the target letter for the detection of the second-P3a. Letters occurred at a rate of one per 500 ms, so the choice of these time intervals allowed us to detect the P3a elicited by both the target letter and the following one.

To explore age-related differences on the peak amplitude of the N2 wave (more specifically the N2b component), we ran a $3 \times 2 \times 2$ ANOVA with electrode sites (C3, Cz, and C4) and N2 type (first-N2 versus second-N2) as within-subjects factors, and age as the between-subjects factor. The time interval was 150–550 ms after the target letter for the detection of the peak amplitude of the first-N2 and 700–1000 ms for the detection of the second-N2.

We restricted the analysis of peak latencies to the first-P3a and the first-N2 given that older adults seemed not to exhibit the second of each from visual inspection. For the analysis of both ERP components, we considered electrode site and age group as factors. All post hoc tests were adjusted for multiple comparisons using Bonferroni correction. When the sphericity assumption was violated, we applied the Huynh–Feldt correction. For all electro-physiological and behavioral statistics, effect sizes were estimated using partial eta squared ($\eta_2^p$).

3. Results

Older adults exhibited slower responses (mean ± SE; 538 ± 49 ms) than younger ones (462 ± 30 ms) [F(1,34) = 31.06, p < .0001, $\eta_2^2$ = .47] and tended to perform worse (93 ± 8% versus 98 ± 4%) [F(1,34) = 3.86, p < .05; $\eta_2^2$ = .10].

As seen in Fig. 1, both younger and older adults exhibit the first-P3a, but only younger ones exhibit the second-P3a. The ANOVA confirmed this, showing a significant age group × type of P3a interaction [F(1,34) = 19.58, p < .0001; $\eta_2^2$ = .37].

Post hoc analysis showed that the first-P3a amplitude was significantly higher in older adults than in younger adults (p < .05), whereas the second-P3a amplitude was significantly higher in younger adults than in older adults (p < .0001). The comparison of the P3a waves within the same age group revealed that in younger adults the first-P3a was less positive than the second-P3a, whereas the opposite pattern was evidenced in older adults, with the second-P3a being almost absent in such age group (all ps < .01).

As shown in Fig. 2, both younger and older adults exhibit the first-N2, which seems even more negative in older adults. In contrast, only younger adults show the second-N2. This pattern is confirmed by the significant age group × type of N2 × electrode site interaction [F(1,68) = 6.70, p < .01, $\eta_2^2$ = .16; ε = .97]. Post hoc analysis revealed greater amplitude of the first-N2 in older adults than in younger adults over Cz electrode (p < .0001). The second-N2 was more negative in younger adults but very reduced or absent in older adults, especially in Cz and C3 electrodes (ps < .0001). Moreover, there was no difference in the amplitude between the first-N2 and the second-N2 in younger adults (all ps > .05), whereas the first-N2
Fig. 1. First-P3a and second-P3a for younger and older adults. (a) Amplitude values of P3a peak as a function of age group, electrode, and type of P3a. (b) Grand average ERPs for the first- and second-P3a at F8 in younger (represented by gray) and older adults (represented by black).

Fig. 2. First-N2 and second-N2 for younger and older adults. (a) Amplitude values of the N2 peak as a function of age group, electrode, and type of N2. (b) Grand average ERPs for the first- and second-N2 at Cz in younger (represented by gray) and older adults (represented by black).
was significantly greater compared to the second-N2 in older adults in C3 and Cz electrodes (all ps < .0001).

Analysis of peak latencies revealed significant age effects for both the first-P3a \( F(1,34) = 5.74, \ p < .05; \ \eta^2_p = .14 \) and the first-N2 \( F(1,34) = 17.18, \ p < .001; \ \eta^2_p = .34 \). Both were significantly delayed in older adults compared to younger adults.

Fig. 3 clearly illustrates these patterns on the scalp maps. The first-P3a and the first-N2 were expressed in both younger adults (scalp maps at 300 ms) and older adults, although they were delayed in this age group (scalp maps at 400 ms). The second-P3a and the second-N2 occurred only in younger adults (scalp maps at 800 ms).

4. Discussion

The present study identified age-related changes in neurocognitive mechanisms underlying attentional tasks. We explored age-related differences in ERPs elicited by the target stimulus and following one. This topic has been surprisingly neglected so far.
Older adults were slower than younger adults to respond to target letters. Also, the latencies of P3a and N2 were delayed for older adults compared to younger adults. This ERP pattern suggests that aging does not slow down only motor preparation/execution but also the attentional processes [5].

The first-P3a and the first-N2 (i.e., the ERPs elicited by the target letter) were greater in older adults compared to younger adults [27,28]. On the other hand, the second-P3a and the second-N2 (i.e., the ERPs elicited by the letter just following the target letter) were much larger in younger adults than in older adults. More specifically, the second-P3a and the second-N2 seem to be somehow absent in older adults.

In line with other studies [2,29], the preservation of the first-P3a and the first-N2 in older adults suggests that advancing age spares the capacity to enhance the processing of target stimuli. Moreover, given that P3a and N2 are associated with attention and control processes, the age-related increase in these components’ amplitude suggests that older adults allocate more attentional and control resources than younger adults to process and respond to stimuli [27].

Nevertheless, unlike younger adults, older adults did not exhibit P3a or N2 for the letter occurring just after the target (Fig. 3), which suggests age-related decline in attention shifting [30]. More specifically, older adults may have taken longer and had more trouble shifting attention from the target to the next letter [24]. Indeed, the lack of these components in the subsequent letter indicates that older adults failed to promptly re-orient and allocate attention to this stimulus. This consideration is also corroborated by the association of P3a and N2 with attention-shifting processes (e.g., [15,31,32]). Moreover, the slowing of processes, specifically attentional processes, significantly worsened performance in the older adults [5]. In fact, if processing a given stimulus takes too much time, the attentional system is less prepared to process the next one.

To sum up, in older adults, the enhancement of first-P3a and first-N2 coupled with the reduction of second-P3a and the second-N2 indicates that older adults allocate additional resources to process target stimuli, but are slowed in shifting attention from such target stimuli to the next ones. In younger adults, the similar amplitudes of P3a and N2 between target letters and following ones indicate they can shift attention and process stimuli more efficiently.

Even if this study was not specifically designed to identify age-related changes in the ERP correlates of attentional blink, it might explain the greater difficulty older adults have in identifying the second of two target stimuli in rapid sequence [22–24]. This seems particularly helpful given that, to the best of our knowledge, age-related changes in the ERP mechanisms underlying the attentional blink have never been explored so far.

Based on our results, the larger attentional blink exhibited by older adults in previous studies seems to be due to older adults’ slower speed and greater difficulty disengaging and shifting attention. Thus, it might not come from specific inhibitory deficits (or, at least, not solely) but also from slower processing speeds and attentional shifts.

To better clarify such issues, future studies should investigate ERPs distinguishing the non-target stimulus that follows the target stimulus from the non-target stimulus that does not. Moreover, an interesting matter of study would be the evaluation of performance and ERPs associated with two consecutive target stimuli occurring in a rapid sequence.

Acknowledgment

We thank Giorgio Arcara for his help in data analysis.

References


2. A. Kok, Age-related changes in involuntary and voluntary attention as reflected in components of the event-related potential (ERP), Biol. Psychol. 54 (2000) 107–143.


17. C. Hölig, S. Berti, To switch or not to switch: brain potential indices of attentional control after task-relevant and task-irrelevant changes of stimulus features, Brain Res. 1345 (2010) 164–175.


