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Age-related differences in the automatic processing of single letters: implications for selective attention

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Abstract

Older adults exhibit diminished ability to inhibit the processing of visual stimuli that are supposed to be ignored. The extent to which age-related changes in early visual processing contribute to impairments in selective attention remains to be determined. Here, 103 adults, ages 18-85, completed a color selective attention task in which they were asked to attend to a specified color and respond to designated target letters. An optimal approach would be to initially filter according to color and then process letter forms in the attend color to identify targets. An asymmetric N170 ERP component (larger amplitude over left posterior hemisphere sites) was used as a marker of the early automatic processing of letter forms. Young and middle-aged subjects did not generate an asymmetric N170 component. In contrast, young-old and old-old subjects produced a larger N170 over the left hemisphere. Furthermore, older adults generated a larger N170 to letter than non-letter stimuli over the left, but not right hemisphere. More asymmetric N170 responses predicted greater allocation of late selection resources to target letters in the ignore color, as indexed by P3b amplitude. These results suggest that unlike their younger counterparts, older adults automatically process stimuli as letters early in the selection process, when it would be more efficient to attend to color only. The inability to ignore letters early in the processing stream helps explain the age-related increase in subsequent processing of target letter forms presented in the ignore color.

Keywords

aging; ERPs; N170; selective attention; P3b

Introduction

Research on selective attention suggests that as individuals get older they become less able to limit attention paid to task-irrelevant stimuli. This age-related difficulty interferes with performance [1-3] and is associated with the appropriation of excessive processing resources to stimuli that are supposed to be ignored [2,4,5]. The ways in which changes in early visual processing may contribute to age-related declines in selective attention remain to be determined.

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In the current study, subjects across a wide range of the adult lifespan were shown a series of red and blue letters, with specific letters designated as targets. Subjects were told to respond to target letters in a designated color and to ignore stimuli in the other color. According to a processing model developed from studies of young adults, we hypothesized that subjects initially select input on the basis of the most easily identifiable physical characteristic (color) and then continue to process more complex features (letter forms) of stimuli in the relevant color in order to identify targets [6-8]. A potential challenge to this hierarchical model of selective attention is the finding that for experienced readers, words are automatically processed, which, for example, manifests in the Stroop interference effect [9].

In ERP studies, the N170 component has been used as an index of the early perceptual processing of stimuli for which individuals have expertise (e.g., faces, word forms). The N170 that is sensitive to word forms is larger over left hemisphere sites [10-12]. If subjects in the current experiment processed individual letters like whole word forms and thus dealt with them in a rapid, automatic fashion, we would expect to find a larger N170 component over the left hemisphere. To the best of our knowledge, no studies have addressed whether there are age-related differences in early visual processing of single letters. If older adults execute the task differently from young adults and treat stimuli in the ignore color as letters early in the information processing stream, it may be very difficult not to process them during late selection. This may contribute to an age-associated increase in P3b amplitude (an index of resource allocation) in response to target letter forms in the ignore color.

Subjects and Methods

Recruitment of subjects took place through community announcements. All subjects underwent informed consent approved by the Partners Human Research Committee. Participants were from one of 4 age groups, labeled young (18-32 years old), middle-aged (40-60), young-old (y-old) (65-79) and old-old (o-old) (80-85). To be included, subjects had to be English-speaking, have ≥ 12 years of education, a Mini Mental State Exam [13] score ≥ 26, and an estimated intelligence quotient (IQ) on the American Modification of the National Adult Reading Test [14] ≥ 100. Subjects were excluded if they had a history of CNS diseases or major psychiatric disorders based on DSM-IV criteria [15], focal abnormalities on neurological examination consistent with a CNS lesion, a history of clinically significant medical or audiological diseases, corrected visual acuity worse than 20/40, or inability to distinguish between the color red and blue. Subjects were paid for their time.

Subjects were shown a series of letters, half of which were in the color red and half in the color blue, presented in random order as detailed in prior reports [7,16]. They were instructed to pay attention to letters appearing in the designated color while ignoring letters appearing in the other color, and to respond by button press to target letters appearing in the designated color only. Task demands were made easier for older subjects to help minimize group differences in performance [16]. Young and middle-aged subjects responded to 5 target letters; y-old and o-old subjects responded to 4 target letters.

The task included 800 stimulus trials divided into 8 blocks. Stimuli subtended an angle of 2.5° along their longest dimension and appeared one at a time for 250 ms. The inter-stimulus interval (ISI) varied randomly between 815-1015 ms. Target stimuli (7.5% in attend color; 7.5% in ignore color) were designated upper case letters. Standard stimuli (35% in each color) were any non-target upper case letters. Novel stimuli (e.g., geometric figures; 7.5% in each color) accounted for the remainder of the stimuli presented.

An ActiveTwo electrode cap (Behavioral Brain Sciences Center, Birmingham, UK) was used to hold to the scalp a full array of 128 Ag-AgCl BioSemi (Amsterdam, The Netherlands) “active” electrodes whose locations were based on a pre-configured montage. Electrodes were arranged in equidistant concentric circles from the 10-20 position Cz. In addition, 6 mini bio-potential electrodes were placed over the left and right mastoid, beneath each eye, and next to the outer canthi to check for eye blinks and vertical and horizontal eye movements. EEG activity was digitized at a sampling rate of 512 Hz.

Demographic variables and behavioral performance of the four groups were compared using ANOVAs. Performance included median reaction time (RT) (within 200-1000 ms) and accuracy rates (% Target Hits – % False Alarms). EEG data were analyzed using ERPLAB (www.erpinfo.org/erplab) and EEGLAB (http://sccn.ucsd.edu/eeglab) toolboxes that operate within the MATLAB framework following the procedures described in previous reports [7,16]. EEG epochs for the 3 stimulus types (standards, targets, novels) across 2 attention conditions (attend, ignore) were averaged separately for trials that had a correct response. Here, we focus on results in response to target letter forms. The latency of the N170 was measured as the local negative peak latency between 100-250 ms at occipito-temporal (O-T) regions of interest (ROIs) over the left and right hemisphere. The amplitude of the N170 was derived from the mean amplitude of the 50 ms interval centered at the mean peak latency for each age group. The latency of the P3b for each group was measured as the local positive peak latency under the attend condition between 400-700 ms in response to target stimuli at the midline electrode site Pz. The size of the P3b was derived from the mean amplitude of the 100 ms interval centered at the mean local peak latency at posterior-medial ROIs of the left and right hemisphere. Each ROI reflected a cluster of 7 electrode sites [7]. The mean amplitude of the N170 and P3b was analyzed using ANOVA, with hemisphere (right, left) and condition (attend, ignore) as within-subject variables, and age group as the between-subject variable.

Results

Table 1 summarizes the subject characteristics and behavioral data for each age group. Of note, there were no differences across groups in education, estimated IQ, or gender.

Grand average ERPs in response to target letters demonstrating the N170 component at left and right O-T ROIs are presented in Figure 1. A 2 condition (attend, ignore) × 2 hemisphere (left, right) × 4 group (young, middle-age, y-old, o-old) ANOVA revealed a group × hemisphere interaction ($F(3,99) = 3.19$, $p < .05$), This interaction was present because for young and middle-aged subjects, there was no difference in the N170 amplitude between left and right sites (no effect of hemisphere, young: $p = .58$; middle-aged: $p = .12$). In contrast, for y-old and o-old subjects, the amplitude of the N170 was larger over the left hemisphere (effect of hemisphere, y-old: $F(1,28) = 8.05$, $p < .01$; o-old: $F(1,21) = 16.89$, $p < .001$). The interaction between group and hemisphere was not modulated by attentional condition. The same pattern of results was also found in response to standard stimuli presented in either the attend or ignore color. To test whether the age-related differences in N170 asymmetry were specific to the processing of letters, we examined the response to the non-orthographic novel stimuli. Y-old and o-old subjects generated a larger N170 to target letters than novel stimuli over the left O-T ROI (effect of stimulus type, y-old: $F(1,28) = 16.95$, $p < .001$; o-old: $F(1,21) = 6.65$, $p < .05$), but not the right O-T ROI, where the size of the N170 did not differ between stimulus types. In contrast, for young and middle-aged subjects the difference between the target and novel N170 did not vary across the two hemispheres.

Grand average ERPs demonstrating the P3b component at posterior-medial ROIs are presented in Figure 2. A 2 condition (attend, ignore) × 2 hemisphere (left, right) × 4 group (young, middle-age, y-old, o-old) ANOVA demonstrated a group × condition interaction ($F(3,99) = 9.38$, $p < .001$). This interaction was present because there was an effect of condition (attend > ignore) for young ($F(1,25) = 79.61$, $p <.001$) and middle-aged ($F(1,25) = 13.08$, $p < .001$) subjects, but not for y-old ($p = 0.12$) or o-old ($p = .59$) subjects.

The degree to which the N170 differed across left and right hemispheres was measured by computing the amplitude of the left minus right O-T ROIs ("asymmetry index"). The N170 asymmetry index correlated with the size of the P3b to target letter forms under the ignore condition ($r = .30$, $p < .01$) and inversely correlated with the difference in P3b between attend and ignore conditions ($r = -.35$, $p < .001$): the larger the N170 asymmetry, the larger the P3b response under ignore, and the smaller the P3b difference between attend and ignore. These correlations remained significant after controlling for age ($r = .20$, $p < .05$; $r = -.28$, $p < .01$, respectively).

Discussion

We investigated age-related differences in the early, automatic processing of single letters as word forms and the potential impact of such changes on selective attention. The four age groups were relatively well-matched for demographics, estimated IQ, and performance, allowing ERP differences between groups to be interpreted as a reflection of age-associated changes and not confounding factors.

There is strong evidence that parts of the O-T cortex are specialized for the perceptual processing of stimuli in which individuals have expertise [17], with the left hemisphere sensitive to prelexical processing of word forms. Letter strings elicit a larger N170 component over left posterior sites [10-12]. The extent to which young adults reliably treat single letters in a manner similar to strings of letters is much less clear. For example, functional imaging studies have varied in the degree to which single letters engage the left fusiform gyrus, in particular the visual word form area [18-20]. The Stroop interference effect is attenuated using a single letter format [21]. The asymmetry of the N170 tends to be smaller and more variable in response to single letters than letter strings [20,22,23]. We are unaware of prior studies that have examined age-related changes in the N170 to single letters or word forms.

In the current investigation, young and middle-aged adults did not produce an asymmetric N170 response to single letters. In contrast, y-old and o-old adults generated a larger N170 to letters over the left hemisphere. Moreover, older subjects produced a larger N170 to letter than non-letter stimuli over left, but not right hemisphere sites, which argues against the observed hemispheric asymmetries as simply reflecting a non-specific age-associated response. Taken together, these results indicate that early in the processing stream, older adults handle single letters like words in a rapid, automatic fashion. In addition, we found that during late selection there was a striking age-related increase in P3b amplitude to target letter forms in the ignore color.

The source of the age-associated difference in N170 asymmetry to single letters remains to be determined. It could reflect an age-related increase in expertise with reading that promotes the automatic engagement of left O-T regions by single letters or an age-associated reduction in the ability to inhibit automatic processing. Studies have shown that young adults can modulate the word N170 when directing attention to letters vs. faces [24] or orthographic vs. semantic features of words [25]. However, in the current study, there is no evidence to suggest that young or middle-aged adults exercise top-down inhibitory control over the N170 component. Specifically, they did not generate a larger or more asymmetric

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N170 to letters under the attend than ignore condition, which might have facilitated task performance.

The N170 findings in older subjects suggest that they do not carry out the selective attention aspects of the task by following the proposed hierarchical processing model, which in the current experiment would suggest that individuals initially select stimuli based on a simple physical characteristic (color), and subsequently process letter forms within the attend color to identify those designated as targets. Theoretically, this approach reduces the processing burden during late selection by approximately half (i.e., stimuli in the ignore color). In contrast to their younger counterparts, older adults treat stimuli as letters early in the processing stream, as indexed by the lateralized N170. Once stimuli in the ignore color have been processed as letters, it may be much more challenging to subsequently disregard them when making decisions about whether stimuli match specific target letter forms. This may help to explain why older adults allocated substantially more resources to target letters in the ignore color than younger adults, as indexed by the P3b amplitude. Consistent with this hypothesized mechanism, the size of the N170 asymmetry index predicted the P3b amplitude in response to target letter forms in the ignore color, a finding that survived controlling for age.

Conclusion

This research demonstrated a clear age-related difference in the way in which single letters are processed. In contrast to their younger counterparts, y-old and o-old adults appear to automatically process single letters in a manner similar to word forms, as indexed by a larger N170 over left than right O-T sites. The inability to disregard letters early in the processing stream likely contributed to the appropriation of excessive resources to target letter forms in the ignore color during late selection, as indexed by the P3b amplitude. It remains to be determined whether there are classes of stimuli other than letters for which older adults have developed greater expertise and more specialized early perceptual processing, which in certain contexts place greater burdens on mechanisms of selective attention.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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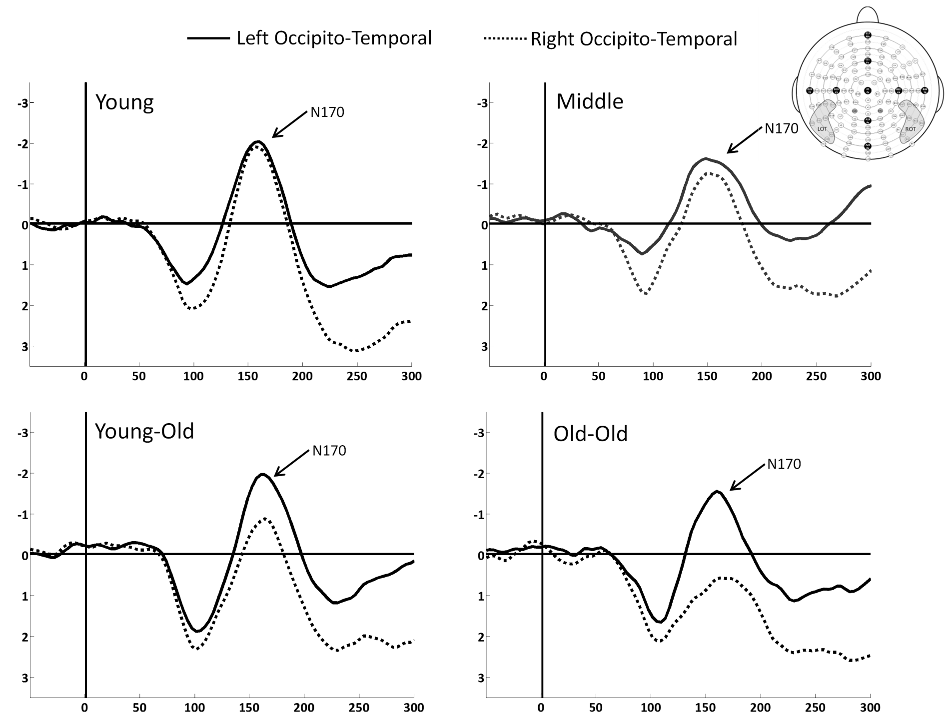

Figure 1.
Grand average ERPs in response to target letters at left occipito-temporal (LOT; solid lines) and right occipito-temporal (ROT; dotted lines) sites, demonstrating an asymmetric (left > right) N170 component for young-old and old-old subjects, but not for young and middle-aged subjects. (Data were collapsed over responses to stimuli in the attend and ignore color because the N170 results were not modified by condition.) The N170 data are presented and analyzed using an average mastoid reference. The same pattern of results was observed when the data were re-referenced using a common average reference.

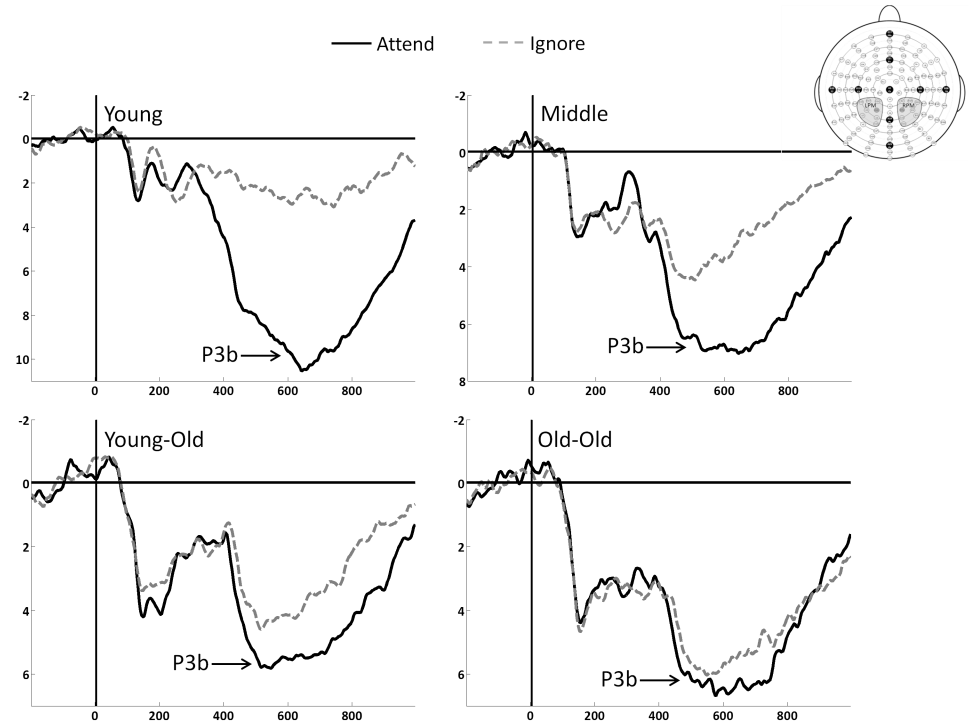

Figure 2.

Grand average ERPs in response to target letters at left and right posterior-medial sites (LPM and RPM) in the attend color (solid lines) and ignore color (dashed lines), demonstrating a large difference in P3b amplitude between conditions for young and middle-aged subjects, but not for young-old and old-old subjects. (Data were collapsed over responses for left and right posterior-medial sites because the P3b results were not modified by hemisphere.)

Table 1

Subject characteristics and behavioral data

	Young	Middle	Young-Old	Old-Old	p value
Number of subjects [1]	26	26	29	22	
Male:Female	13:13	10:16	14:15	9:13	ns
Age	22.6 (2.2)	50.9 (6.5)	72.8 (3.9)	82.7 (1.9)	< .00001
Education (years)	15.2 (1.5)	16.7 (2.5)	16.2 (3.2)	16.7 (3.3)	ns
AMNART (estimated IQ)	116.7 (6.7)	118.5 (8.4)	118.3 (9.8)	120.3 (9.3)	ns
MMSE	29.9 (.4)	29.3 (.8)	29.4 (.8)	29.3 (1.0)	< .05[2]
Median RT	591 (56)	619 (80)	629 (60)	638 (77)	< 0.1[3]
Accuracy	88.3 (7.5)	90.7 (7.4)	91.3 (7.6)	87.8 (12.1)	ns

[1] An additional 3 young, 6 middle-aged, 5 young-old, and 6 old-old subjects participated in the experiment, but were excluded due to excessively noisy ERP data.

[2] Young had a higher score than all other groups (all p values < .05)

[3] Young were faster than young-old (p < .05) and old-old (p < .05)

AMNART = American National Adult Reading Test

MMSE = Mini Mental State Exam

Accuracy = % Target Hits - % False Alarms

ns = not significant