NeuroImage 67 (2013) 127–136

Contents lists available at SciVerse ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

The impact of visual acuity on age-related differences in neural markers of early visual processing

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ARTICLE INFO

Article history:
Accepted 26 October 2012
Available online 13 November 2012

Keywords:
Aging
Visual processing
Visual acuity
ERPs

ABSTRACT

The extent to which age-related differences in neural markers of visual processing are influenced by changes in visual acuity has not been systematically investigated. Studies often indicate that their subjects had normal or corrected-to-normal vision, but the assessment of visual acuity seems to most frequently be based only on self-report. Consistent with prior research, to be included in the current study, subjects had to report normal or corrected-to-normal vision. Additionally, visual acuity was formally tested using a Snellen eye chart. Event-related potentials (ERPs) were studied in young adults (18–32 years old), young–old adults (65–79 years old), and old–old adults (80+ years old) while they performed a visual processing task involving selective attention to color. Age-related differences in the latency and amplitude of ERP markers of early visual processing, the posterior P1 and N1 components, were examined. All results were then re-analyzed after controlling for visual acuity. We found that visual acuity declined as a function of age. Accounting for visual acuity had an impact on whether older and younger adults differed significantly in the size and latency of the posterior P1 and N1 components. After controlling for visual acuity, age-related increases in P1 and N1 latency did not remain significant, and older adults were found to have a larger P1 amplitude than young adults. Our results suggest that until the relationship between age-associated differences in visual acuity and early ERPs is clearly established, investigators should be cautious when interpreting the meaning of their findings. Self-reports about visual acuity may be inaccurate, necessitating formal measures. Additional investigation is needed to help establish guidelines for future research, especially of very old adults.

Introduction

A large body of research suggests that there are age-related differences in visual processing (Ceponiene et al., 2008; Davis et al., 2008; De Sanctis et al., 2008; Dennis and Cabeza, 2008; Diaz and Amenedo, 1998; Dustman and Beck, 1966; Dustman and Snyder, 1981; Finnigan et al., 2011; Goh, 2011; Schmolesky et al., 2000; Spear, 1993; Yu et al., 2006; Zanto et al., 2010). There is also strong evidence of age-associated declines in visual acuity (Faubert, 2002; Kanthan et al., 2008; Klaver et al., 1998; Munoz et al., 2000; Rodriguez et al., 2002; Rubin et al., 1997; Spear, 1993). However, the extent to which age-related differences in measures of cortical visual processing are influenced by changes in visual acuity has not been systematically investigated. In this study, we focus on two early event-related potentials (ERPs), the posterior P1 and the posterior N1 components, and investigate whether the age-associated differences observed may be related to changes in visual acuity.

The posterior P1 and N1 components are mediated by extra-striate regions and index initial sensory-perceptual encoding (Hillyard et al., 1998b; Mangun et al., 1990; Natale et al., 2006; Schechter et al., 2005; Woldorff et al., 1997). The P1 component is hypothesized to reflect early cortical processing of stimuli sensitive to bottom-up influences such as stimulus salience and complexity (Hillyard et al., 1998a; Johannes et al., 1995), and the N1 component is theorized to reflect initial visual discrimination processing and early visual categorization (Hillyard et al., 1998a; Martinovic et al., 2011; Vogel and Luck, 2000). Both components are sensitive to spatial attention, but under most circumstances are not modulated by selective attention to non-spatial features such as color (Daffner et al., 2012a, 2012b; Hillyard and Anllo-Vento, 1998; Hillyard and Munte, 1984).

Usually, age-related changes in P1 and N1 have been interpreted in terms of the impact that aging has on cortical visual processing (Ceponiene et al., 2008; De Sanctis et al., 2008; Diaz and Amenedo, 1998; Dustman and Beck, 1966; Dustman and Snyder, 1981; Finnigan et al., 2011; Zanto et al., 2010). Limited attention has been paid to the potential influence of age-associated differences in visual acuity on electrophysiological measures. Most investigations report that

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http://dx.doi.org/10.1016/j.neuroimage.2012.10.089

subjects had normal or corrected-to-normal vision (Ceponiene et al., 2008; Czigler and Balazs, 2005; De Sanctis et al., 2008; Falkenstein et al., 2006; Finnigan et al., 2011; Yordanova et al., 2004; Zanto et al., 2010). However, in most cases there is no indication that visual acuity was actually measured, and it is likely that the investigators largely relied on reports from subjects about their visual status. Only a few studies measured visual acuity (e.g., Celesia and Daly, 1977; Curran et al., 2001; De Sanctis et al., 2008; Diaz and Amenedo, 1998; Zanto et al., 2010). Of these studies, some set inclusion/exclusion cutoffs of 20/20 (Celesia and Daly, 1977), 20/30 (Diaz and Amenedo, 1998), or 20/40 (Zanto et al., 2010), whereas others did not establish clear cutoff scores (Curran et al., 2001; Werkle-Bergner et al., 2009). For example, Curran et al. (2001) reported that the mean visual acuity for their sample of older subjects (mean age 69.8) was 20/46, with a range from 20/20 to 20/100. We are not aware of any previous investigations that have accounted for differences in visual acuity when interpreting the significance of age-related differences in early visual ERPs.

To address this gap in the literature, we studied three age groups: young adults (18–32 years old), young–old adults (65–79 years old), and old–old adults (80+ years old) who performed a visual processing task involving selective attention to color. Consistent with many studies, all subjects were initially screened (by telephone interview) for normal or corrected-to-normal vision based on self-report. As part of the evaluation of participants, subjects underwent testing of visual acuity using a Snellen eye chart. Age-related differences in the latency and amplitude of the P1 and N1 components were examined. All results were then re-analyzed after controlling for visual acuity. The relative lack of attention to this factor in the literature led to the expectation that it would have a limited impact on the findings. Nevertheless, we reasoned that if substantial changes in our results were found after controlling for visual acuity, it would suggest the need for investigators to be more cautious about interpreting age-associated differences in P1 and N1 components in terms of changes in cortical visual processing activity. Moreover, it would call upon researchers to include formal measures of visual acuity in future studies.

Methods

Participants

Subjects were recruited through community announcements in the Boston metropolitan area, including the Harvard Cooperative Study on Aging. All subjects underwent informed consent approved by the Partners Human Research committee. Participants were between 18 and 32 years or 65 and older. All subjects underwent an initial telephone screen in which they were asked about vision, hearing, and medical history. To be included in this study subjects had to report that they had normal vision or corrected-to-normal vision with glasses or contact lenses. In addition, inclusion criteria required that subjects be English-speaking and have 12 or more years of education, a Mini Mental State Exam (MMSE) score (Folstein et al., 1975) ≥ 26, and an estimated Intelligence Quotient (IQ) on the American National Adult Reading Test (AMNART) (Ryan and Paolo, 1992) ≥ 100. Subjects were excluded if they had a history of CNS diseases or major psychiatric disorders based on DSM-IV criteria (American Psychiatric Association, 1994), a history of clinically significant medical diseases, a history of clinically significant audiological disease, a Beck Depression Inventory (Beck and Steer, 1987) (for young subjects) or a Geriatric Depression Scale (Yesavage et al., 1982) (for old subjects) score of ≥ 10, were unable to distinguish between the colors red and blue, or had focal abnormalities on neurological examination consistent with a CNS lesion. Subjects were paid for their time.

Binocular visual acuity was measured in all subjects with the Snellen 10 ft model wall chart, and recorded as a decimal representation of 20/x, such that 20/20 = 1.0 and represents "normal" visual acuity. Worse than normal vision was represented with a visual acuity value of less than 1.0 (e.g., 20/40 = 0.5). Better than normal vision was represented with a visual acuity value greater than 1.0. All subjects underwent a neuropsychological test battery that included the following: Digit Span Forward and Backward subtests of the Wechsler Adult Intelligence Scale-IV (WAIS-IV) (Wechsler, 2008), WAIS-IV Letter-Number Sequencing, WAIS-IV Digit-Symbol Coding, WAIS-IV Matrix Reasoning, Controlled Oral Word Association Test (COWAT) (Ivnik et al., 1996), Trail-Making Test Parts A and B (Reitan and Wolfson, 1985), Boston Naming test (Tombaugh and Hubley, 1997), Logical Memory II subtest of the Wechsler Memory Scale-III (Wechsler, 1997), and Visual Form Discrimination (Benton et al., 1983).

Experimental procedures

A selective attention task was administered under low and high memory load. Under both loads, subjects were shown physically identical sets of stimuli, which consisted of individual letters presented in either the color red or the color blue. The low load task required subjects to respond by button press to one specific target letter. To help minimize group differences in performance on the high load task, demands were made easier for old subjects. For the high load task, the number of target letters chosen for each age group was based on pilot data: young subjects responded to 5 target letters and older subjects responded to 4 target letters. This was done to allow us to draw inferences about age-related differences in neural activity and not performance-related differences (Daffner et al., 2011; Daselaar and Cabeza, 2005; Riis et al., 2008). Subjects were instructed to pay attention to letters appearing in the designated color while ignoring letters appearing in the other color, and respond to target letters appearing in the designated color only. Subjects were asked to respond as quickly and as accurately as possible to target letters. Practice trials preceded each set of experimental runs. All subjects participated in both tasks, whose order was counterbalanced. The hand used for the target response was counterbalanced across subjects.

Each task included 800 stimulus trials divided into 8 blocks. In both the high load and low load tasks, stimuli appeared one at a time within a fixation box that remained on the screen at all times and subtended a visual angle of ~3.5° × 3.5° at the center of a high-resolution computer monitor. Half of the stimuli appeared in the color red and half in the color blue, in randomized order. Target stimuli (7.5% in attend color; 7.5% in ignore color) were designated upper case letters and standard stimuli (70% overall; 35% in each color) were any non-target upper case letters. Fillers accounted for the remainder of the stimuli presented. Visual stimuli subtended an angle of ~2.5° along their longest dimension and were presented for 250 ms. The inter-stimulus interval (ISI) varied randomly between 815 and 1015 ms (mean ~ 915 ms) (see Fig. 1). For analytic purposes, trials were categorized in terms of whether the stimuli presented were in the attend or the ignore color. The Attend condition consisted of all stimuli in the designated color; the Ignore condition consisted of all stimuli in the non-designated color.

ERP recordings

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 10 to 20 system position Cz. In addition to the 128 electrodes on the scalp, 6 mini bio-potential electrodes were placed over the left and right mastoid, beneath each eye, and next to the outer canthi of the eyes to check for eye blinks and vertical and horizontal eye movements. EEG activity was digitized at a sampling rate of 512 Hz.

Data analysis

To create a composite score for neuropsychological tests, raw scores on each test were converted into z-scores based on the