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Investigating age-related changes in anterior and posterior neural activity throughout the information processing stream

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ABSTRACT

Event-related potential (ERP) and other functional imaging studies often demonstrate age-related increases in anterior neural activity and decreases in posterior activity while subjects carry out task demands. It remains unclear whether this "anterior shift" is limited to late cognitive operations like those indexed by the P3 component, or is evident during other stages of information processing. The temporal resolution of ERPs provided an opportunity to address this issue. Temporospatial principal component analysis (PCA) was used to identify underlying components that may be obscured by overlapping ERP waveforms. ERPs were measured during a visual oddball task in 26 young, 26 middle-aged, and 29 old subjects who were well-matched for IQ, executive function, education, and task performance. PCA identified six anterior factors peaking between ~140 ms and 810 ms, and four posterior factors peaking between ~300 ms and 810 ms. There was an age-related increase in the amplitude of anterior factors between ~200 and 500 ms, and an age-associated decrease in amplitude of posterior factors after ~500 ms. The increase in anterior processing began as early as middle-age, was sustained throughout old age, and appeared to be linear in nature. These results suggest that age-associated increases in anterior activity occur after early sensory processing has taken place, and are most prominent during a period in which attention is being marshaled to evaluate a stimulus. In contrast, age-related decreases in posterior activity manifest during operations involved in stimulus categorization, post-decision monitoring, and preparation for an upcoming event.

1. Introduction

Functional neuroimaging studies commonly report an age-associated increase in anterior neural activity when subjects carry out a task (Davis, Dennis, Daselaar, Fleck, & Cabeza, 2008; Grady, 2000; Reuter-Lorenz & Sylvester, 2005). The current temporal resolution of fMRI limits the ability to determine when along the information processing stream these age-related differences take place. However, this issue can be effectively addressed through the investigation of event related potentials (ERPs). Most ERP studies have focused on the age-related augmentation in frontal activity during relatively late processing, as indexed by the anterior P3 (P3a) component (Alperin, Mott, Rentz, Holcomb, & Daffner, 2014b; Fabiani, Friedman, & Cheng, 1998; Friedman, Kazmerski, & Fabiani, 1997; West, Schwarb, & Johnson, 2010). An outstanding question involves the extent to which the age-associated increase in anterior activity is limited to late cognitive operations or is present throughout the information processing stream. It is also unclear whether the age-related augmentation in anterior activity reflects a maladaptive or compensatory response (Friedman et al., 1997; Reuter-Lorenz et al., 2000; Riis et al., 2008; West et al., 2010).

In addition to the common finding of an age-related increase in anterior activity, ERP researchers often report an age-related decrease in posterior activity (Ally, Simons, McKeever, Peers, & Budson, 2008; Anderer, Semlitsch, & Saletu, 1996; Fjell & Walhovd, 2001; Friedman et al., 1997; Wolk et al., 2009). For example, in ERP research, older individuals frequently exhibit a smaller posterior P3b (Anderer et al., 1996; Fjell & Walhovd, 2001; Friedman et al., 1997) or late positive component (LPC) (Ally et al., 2008; Wolk et al., 2009) than younger adults. It remains to be determined whether age-related reductions in posterior activity are limited to late cognitive operations or occur throughout the processing stream.

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Most ERP studies examine age-related differences through traditional analyses of averaged waveforms. Although valuable, this form of analysis does not allow one to disentangle temporally and/or spatially overlapping components. In the current study, we used temporospatial PCA, following a method developed by Dien (2010a). PCA is a data driven method that decomposes ERP waveforms into their underlying components and is particularly useful in separating spatially and/or temporally overlapping components. Temporospatial PCA takes advantage of this method's ability to parse components both temporally and spatially by breaking down each temporal principal component into a series of spatially distinct components. In our previous work using PCA, we found that during the temporal interval of the P3a (400–600 ms), older individuals generated a larger response that was interpreted as reflecting increased utilization of anterior neural resources (Alperin, Mott, Holcomb, & Daffner, 2014a; Alperin et al., 2014b). Here, our approach using PCA was broadened to identify distinct anterior and posterior components in addition to the P3, and determine whether they exhibit age-associated differences in amplitude.

Many previous studies, including our own (Alperin et al., 2014a, 2014b), have investigated age-related differences and limited their comparison to young (college-aged) vs. old (~70 years) adults (Fabiani et al., 1998; Lorenzo-Lopez, Amenedo, Pazo-Alvarez, & Cadaveira, 2007; West et al., 2010). This approach, however, does not allow for the examination of changes that may take place over the adult life span. In the current study, we addressed this limitation by including young, middle-aged, and old subjects ranging in age from 19 to 79 years old. This age-range allowed us to determine whether the most prominent changes emerge during old age (>65 years old) or begin during middle age, and whether the age-related differences are linear in nature. Based on prior work (Daffner, Alperin, Mott, Tusch, & Holcomb, 2015; Riis et al., 2009), we expected to find age-related increases in anterior activity beginning around the temporal interval of the anterior P2 component (~150–200 ms) and age-related decreases in posterior activity beginning around the temporal interval of the P3b (~400–600 ms). Moreover, we anticipated that changes would be observed by middle age (Riis et al., 2008).

2. Methods

2.1. Participants

See Table 1 for subject characteristics, including demographic information, neuropsychological test performance, and estimated IQ for each age group. 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 and a detailed screening evaluation that included a structured interview to obtain a medical, neurological, and psychiatric history; a formal neurological examination; the completion of a neuropsychological test battery; and questionnaires surveying mood and socioeconomic status.

To be included in this study, participants had to be between the ages of 18 and 32 (young), 40 and 60 (middle-aged), or 65 and 79 (old), be English-speaking, have ⩾ 12 years of education, have a Mini-Mental State Exam (MMSE) (Folstein, Folstein, & McHugh, 1975) score ⩾ 26, and an estimated intelligence quotient (IQ) on the American National Adult Reading Test (AMNART) (Ryan & 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), focal abnormalities on neurological examination consistent with a CNS lesion, a history of clinically significant medical diseases, corrected visual acuity worse than 20/40 (as tested using a Snellen wall chart), a history of clinically significant audiological disease, a Beck Depression Inventory (Beck & Steer, 1987) score ⩾10 (for young and middle-aged subjects) or a Geriatric Depression Scale (Yesavage et al., 1983) score ⩾10 (for old subjects), or were unable to distinguish between the color red and blue. Subjects were paid for their time.

Table 1
Subject characteristics, accuracy, and mean RT (mean (SD)).

	Young	Middle-aged	Old
Number of subjects	26	26	29
Gender (male:female)	13:13	11:15	14:15
Age (years)**	22.58 (2.21)	50.92 (6.48)	72.83 (3.85)
Executive capacity (% ile)	67.38 (16.74)	69.38 (16.90)	68.61 (15.87)
Years of education	15.15 (1.54)	16.67 (5.53)	16.19 (3.20)
AMNART (estimated IQ)	116.73 (6.68)	118.54 (8.35)	118.31 (9.77)
MMSE*	29.85 (.37)	29.31 (.79)	29.41 (.82)
Accuracy (%)	88.25 (7.45)	90.69 (7.39)	91.26 (7.58)
Mean RT (ms)	610 (52)	631 (75)	644 (60)

Executive capacity = Average (composite) percentile performance (relative to published age-matched norms) on the following tests: Digit Span Backward, Controlled Oral Word Association Test, Letter-Number Sequencing, Trail-Making Test Parts A and B, and Digit-Symbol Coding.
AMNART = American National Adult Reading Test.
MMSE = Mini-Mental State Exam.
Accuracy = % target hits − % false alarms.
* Effect of age group, $p < .05$ (young > middle-aged = old).
** Effect of age group, $p < .001$ (young < middle-aged < old).

To appropriately interpret age-related changes in neural activity, it is crucial to minimize differences between groups in cognitive abilities and task performance. If not, observed differences between groups may be due to factors other than age (Daffner et al., 2011b; Daselaar & Cabeza, 2005; Riis et al., 2008). Most investigations have not explicitly addressed this challenge. Due to strong support for the idea that selective attention reflects top-down control mechanisms (de Fockert, Rees, Frith, & Lavie, 2001; Gazzaley et al., 2008; Rissman, Gazzaley, & D'Esposito, 2009; Zanto, Rubens, Thangavel, & Gazzaley, 2011), we made an effort to match age groups in terms of executive capacity. One challenge to accomplishing this goal is the absence of a universally accepted operational definition of executive functions. We followed the suggestion of many investigators who emphasize processes that include working memory, initiation, monitoring, and inhibition, and advocate the use of at least several neuropsychological tests to assess this complex group of functions (Chan, Shum, Toulopoulou, & Chen, 2008; Delis, Kaplan, & Kramer, 2001; Spreen & Strauss, 1998). We selected tests that had well established norms across a wide range of ages. Tests of executive functions included: (1) Digit Span Backward subtest of the Wechsler Adult Intelligence Scale-IV (WAIS-IV) (Wechsler, 2008) measures maintenance and manipulation operations of working memory. (2) Controlled Oral Word Association Test (COWAT) (Ivnik, Malec, Smith, Tangalos, & Petersen, 1996) indexes initiation, self-generation, and monitoring. (3) WAIS-IV Letter-Number Sequencing assesses maintenance, monitoring, and manipulation. (4) WAIS-IV Digit-Symbol Coding assesses sustained attention/persistence, cognitive speed and efficiency. (5) Trail-Making Test Parts A and B (Reitan & Wolfson, 1985) measure planning/sequencing, set shifting, and inhibition.

Executive capacity was defined as the composite percentile performance (relative to age-matched norms) on the six tests of executive function listed above. To meet criteria for the study, subjects needed to perform in the top two thirds (⩾33rd percentile) relative to age-appropriate norms. We did not include subjects who scored in the bottom third on neuropsychological tests to help