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Life-span changes in P3a

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Abstract

The relationship of visual P3a to age was investigated in a life-span sample. The aims of the study were (1) to assess to what extent P3a, relative to P3b, decreases with increasing age; (2) To assess at which recording sites the relationship between P3a and age is strongest; (3) to investigate whether the relationship between P3a and age is best described as linear or nonlinear. One hundred and three well-functioning adults, 20–92 years old, were given a health interview, a battery of neuropsychological tests, and performed a visual three-stimuli oddball ERP task yielding both a P3a and a P3b. P3a and age was moderately correlated, with coefficients reaching .53 (Cz) and −.52 (Pz) for latency and amplitude, respectively. P3b was to a much lesser extent related to age. Generally, the age–P3a relationship was strongest at midline and central electrodes. Finally, the relationship between age and P3a was best described as linear. P3a seems selectively more impaired with age than P3b, but this impairment seems less pronounced at Fz than at Cz and Pz. There is a need for complex theoretical integration of these and previous findings.

Descriptors: ERP, P3a, P3b, Aging, Cognition, Topography

The traditional P3, the P3b, is a positive-going potential with parietal maximum amplitude, and a peak latency of about 300–400 ms in young adults. P3b is related to normal as well as pathological age changes (e.g., Barrett, Neshige, & Shibasaki, 1987; Brown, Marsh, & LaRue, 1983; Fein & Turetsky, 1989; Fjell & Walhovd, 2001, 2003a, 2003b, 2003c; Goodin, Squires, Henderson, & Starr, 1978; Hömberg et al., 1986; Iragui, Kutas, Mitchiner, & Hillyard, 1993; Picton, Stuss, & Champagne, 1984; Polich, 1996; Walhovd & Fjell, 2001, 2002). The P3 is appealing as a physiological measure of age changes in cognitive functions because the component may shed light on behaviorally nonobservable processes, does not demand motor function, and is less affected by motivational state than behavioral measures are (Reinvang, 1998, 1999). A subcomponent of the P3, coined the P3a, seems promising as an index of cognitive age-related changes, but age effects on P3a remain to be assessed in a systematic, large-scale fashion. The aim of this article is to investigate how P3a, relative to P3b, relate to adult age changes in a large sample.

P3b is typically elicited by tasks wherein two types of stimuli of unequal probability are presented, and attention is to be paid to the infrequent ones. P3b latency is often regarded as a measure of the relative timing of the stimulus evaluation process (Coles & Rugg, 1995), and P3b amplitude is held to index resource allocation (Polich, 1996). The so-called P3a is often elicited when a third, infrequent type of deviant nontarget stimuli is inserted into the sequence of target and standard stimuli. The P3 elicited to these deviant stimuli has a peak latency at about 250–400 ms, a fronto-central or central maximum amplitude, and has previously been found to habituate more rapidly than P3b. P3a may reflect involuntary, transient allocation of attention to salient stimuli changes and novel stimuli (Courchesne, Hillyard, & Galambos, 1975; Kaipio et al., 1999).

In one variant of the three-stimulus paradigm, infrequent nontarget visual stimuli that are easily recognized have been found to elicit a P3 with maximum amplitude over the central-parietal rather than frontal/central areas (Courchesne, 1978; Courchesne, Hillyard & Galambos, 1978). Comerchero and Polich (1999) have shown that when target/standard discrimination is easy, P3 to target (P3b) was relatively larger than P3 to nontarget (P3a) across all electrodes. In contrast, when target/standard discrimination was difficult, target amplitude (P3b) was larger parietally and occurred later than nontarget components (P3a), and nontarget amplitude (P3a) was larger and earlier than the target P3 over the frontal electrode sites. Further, Comerchero and Polich (1998) have shown that when the distinctiveness of target versus an infrequent nontarget (distractor) is high, the P3 amplitude to the distractor is larger than the P3 to target, even though they were only able to show this pattern for auditory stimuli. They conclude that when target/standard discrimination is difficult and the nontarget/standard difference is large, the nontarget stimulus elicits a P3 that is greater in amplitude

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frontally and shorter in latency than the target P3. This indicates that the P3 to nontarget exhibits the main characteristics of the P3a.

Intracerebral recordings (Baudena et al., 1995; Halgren, Marinkovic, & Chauvel, 1998), event-related fMRI studies (Clark, Fannon, Lai, & Bauer, 2000), and patient studies (Knight, 1984), indicate that different neural generators exist for P3a and P3b. P3b is associated with neural activity in a wide range of brain regions, and is best observed parietally. The P3a has an anterior scalp distribution, shorter latency, habituates rapidly, and has been interpreted as reflecting frontal lobe function (Katayama & Polich, 1998; Knight, 1984). There have been important studies, but with differing samples and paradigms, and complex interpretations are needed. For instance, Knight has reported decreased P3a in patients with prefrontal lesions (e.g., Knight, 1984), while Kaipio et al. (1999) found enhanced P3a amplitude in closed head injury patients, of whom more than half had focal frontal injuries. The enhanced amplitude may be seen as evidence for greater distractibility in the patient group. Halgren et al. (1998) have suggested that P3a is associated with a separate system related to orientation of attention and centred in paralimbic and attentional frontoparietocingular cortex, whereas the P3b is associated with cognitive contextual integration, a system including ventral temporofrontal event-coding cortices and association cortices as well as the hippocampus. Given the specifically frontal neural origin of P3a and the more widespread neural origin of P3b, one might expect the former to be selectively more impaired than the latter by age processes seen to cause selective frontal neural loss.

P3b shows a posterior to anterior shift with age, that is, a more even distribution of activity (e.g., Friedman, Kazmerski, & Fabiani, 1997; Pfefferbaum, Ford, Wenegrat, Roth, & Kopell, 1984; Vesco, Bone, Ryan, & Polich, 1993). This indicates neural changes in these areas, and is related to decreased performance on tests of general mental ability (Fabiani, Friedman, & Cheng, 1998). It is not known whether the more frontally based P3a also undergoes a frontal shift with age. Fabiani and Friedman (1995), in a study of novelty P3a, observed that young adults ($n = 8$) showed a relatively more frontally oriented scalp focus to the novelty stimuli than older subjects ($n = 8$), a replication of an earlier study by Friedman, Simpson, and Hamberger (1993). Little is known, however, of how normal age changes in frontal function influence P3a. One might expect that greater distractibility or disinhibition may enhance P3a. On the other hand, frontal neural loss with age may diminish P3a.

In the present study, we expect to see P3a to an improbable nontarget (the distractor) inserted into the string of standard and target stimuli. However, some disagreement exists about how P3a should be elicited, and whether different ways of eliciting P3a indeed yield the same electrophysiological responses. To avoid unnecessary confusion, we will, in the rest of the article, avoid the terms “P3a” and “P3b,” and instead use “P3 to distractor” and “P3 to target” as denotations of the relevant waveforms. In the last section, we will discuss the relationship between P3a/P3b and the waveforms attained to the distractor and the target stimuli.

Rationale for the Present Study

Three questions are investigated.

1. How strong is the relationship between age and P3 to distractor? This is explored relative to the relationship between P3 to target and age. The latency of P3 to target was previously found to be robustly related to age. In a meta-analysis of P3 normative aging studies, Polich (1996) presented seven studies that employed a visual oddball task. The median P3 latency–age correlation was .54 (range .33–.63), and the median slope was 1.32 (range 0.80–1.50). For amplitude, the results from previous studies have been less clear (Polich, 1996), especially for visual stimuli. For instance, Pfefferbaum et al. (1984) found no significant relationships between age and visual P3 to target, while Picton et al. (1984) reported a slope of $-0.25\,\mu$V ($r = -.54$), and Polich (1997) found correlations between $-.24$ and $-.33$ along the midline electrodes. Differences between studies are probably partly a result of differences in stimuli and ERP paradigms used. However, little is known about the relationship between P3 to distractor and age. Walhovd and Fjell (2001) reported correlations between age and P3 to distractor at Pz of $-.56$ and .72 for amplitude and latency, respectively, but with an auditory task and a smaller, polarized sample ($n = 31$) of a young and an old group. Given the view of P3 to distractor as reflecting frontal function and earlier findings in patient samples with frontal injuries (Kaipio et al., 1999; Knight, 1984), one will, according to theories of selective frontal cognitive decline with age, expect changes in P3 to distractor in one of two ways: (a) P3 to distractor could, relative to P3 to target, be selectively impaired with age due to selective frontal neuronal loss, analogous to Knight’s findings on frontal injuries as diminishing P3a/automated orienting, or (b) P3 to distractor could, relative to P3 to target, be selectively enhanced with age, analogous to Kaipio et al.’s findings on frontal injuries as enhancing P3a/distractability.
2. At which recording sites is the relationship between P3 to distractor and age strongest? P3 to target gets a more anterior scalp distribution with increasing age, decreasing correlations between age and amplitude of P3 to target at frontal recording sites. One does not know whether this also is the case for P3 to distractor. Given the more fronto-central maximum, our guess is that the commonly observed posterior–anterior shift will be less pronounced for P3 to distractor than for P3 to target, because the frontal and central areas are more active also in the young participants. Further, we hypothesize that P3 to distractor will be moderately correlated with age at the midline electrodes, especially at Cz and Pz, and that the relationship will diminish at the lateral electrodes, where P3 is less pronounced.
3. Are P3 to distractor and age related in a linear or nonlinear fashion? Most report a linear relationship with age when a formal test of this question has been performed in studies of P3 to target (Michalewski, Patterson, Bowman, Litzleman, & Thompson, 1982; Picton et al., 1984), but the question has not been extensively studied with regard to P3 to distractor. Based on knowledge of P3 to target, we hypothesize that the relationship between P3 to distractor and age is best described by a linear function.

Materials and Methods

Sample

The participants were 103 volunteers, aged 20 to 88 years (mean $= 48.4$, $SD = 21.8$, mean education $= 15.3$ years, $SD = 2.5$, 57 women), recruited among employees from a local hospital, through charity organizations, activity centers for the elderly, and newspaper ads. They were given a moderate sum of money to refund possible costs related to their participation. All participants were community dwellers and were screened for chronic diseases, head traumas, and neuropsychological deficits by a battery of neuropsychological tests and health-related questions. Mean IQ was 115, range 87 to 136, not significantly related to age. For some analyses, the sample was divided into three age groups: young participants, aged 20–44 years ($n = 46$, mean age 27.3 years), middle-aged participants, aged 45–69 years ($n = 31$, mean age 54.6 years), and old participants, aged 70–90 years ($n = 26$, mean age 78.4 years).

ERP Stimuli

We used a three-stimuli visual oddball task with a total of 210 stimuli, .10 target and .10 distractor probability, based on the one recommended by Comerchero and Polich (1999). The main difference between the task from Comerchero and Polich and the task in the present study is that the stimuli in the latter are much bigger, and the discrimination between the target and the distractor is assumed to be somewhat easier. The stimuli were presented on a 21-in. computer screen with a black background color, and the distance from the participants' eyes to the screen was about 100 cm, with a visual field of about 9° × 7°, 10° × 8°, and 12° × 10° for the standard, target, and distractor stimuli, respectively. The standard stimuli, to which the participant is told not to respond, are blue elliptic shapes with a height of 15 cm and a width of 12.5 cm. The targets, to which the participant is told to press a button, are blue elliptic shapes with height and width of 17.5 and 14.5 cm, respectively. The distractor stimuli, which the participant is told to ignore, are blue rectangles of 21 × 17 cm.The small difference between targets and standards and the large difference between targets and distractors were chosen to maximize the P3a curve. Presentation time was 0.5 s. ISI was 1.5 s. An example task with 11 stimuli was presented to ascertain that all participants could discriminate targets from standards. Cutoff criteria was set to 20% target misses, 20% responses to standards, or 25% responses to distractors, which led to the exclusion of 4 participants, reducing the total sample to 103. Mean reaction time after cutoff criteria were applied was 520 ms, and mean rate of target hits was 96%.

ERP Procedures

Participants were seated in a reclining chair within a sound-attenuating recording chamber. The electrodes were placed in accordance with the international 10–20 system. For 96 participants, a total of 20 electrodes (Ag/AgCl) were used for recording; Fp1, Fp2, F7, F3, Fz, F8, F4, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, and O2, referred to the left mastoid. For 7 participants, only the midline electrodes (Fz, Cz, Pz, Oz) were used. A VEOG channel was obtained by placing one electrode above and one below the left eye. Ground was placed anteriorly. Interelectrode impedance was generally measured to be less than 10 kΩ. For the recording of EEG activity, A/D rate was 500 Hz, filter setting was 0.10 Hz (high pass) and 70 Hz (low pass). A 50-Hz notch filter was applied. The signals were amplified by a SynAmp DC amplifier (Neuroscan Inc.). Epochs were rejected from averaging if amplitude exceeded $\pm 110\ \mu V$, and eye blinks were corrected for statistically in accordance with Semlitsch, Anderer, Schuster and Presslich's (1986) recommendations. Averaging was performed for targets and distractors separately. EEG was segmented in epochs of 900 ms duration (– 100 ms to 800 ms relative to stimulus onset). All data average files were digitally filtered (15 Hz low pass) and baseline corrected before statistical measures of component latency or amplitude were made. Neuroscan software was used to present stimuli, record, and analyze EEG activity. P3 s were determined algorithmically, in accordance with Pfefferbaum, Ford, and Kraemer's (1990) recommendations, defined as the most positive point constituting a peak within 250 and 650 ms post stimulus (Pfefferbaum et al., 1990).

Statistical Analyses

Pearson's correlations were calculated to investigate the strength of the relationship between P3 to distractor and age and P3 to target and age. Bonferroni corrections of probability level were used in addition to the normal $p < .05$ criterion to adjust for the number of comparisons made. However, the different electrodes are intercorrelated, and this correction method may therefore not be entirely appropriate. ANOVAs with three age groups × latency/amplitude to P3 to distractor/target in turn were used to assess effects of age groups on P3. ANOVAs with three age groups × three electrodes (Fz, Cz, Pz) were performed to explore main effects of age on the topography of the P3 s along the midline recording sites. To assess where the relationship between P3 to distractor and age were strongest, we performed tests of significance of the differences of the correlations at Pz, Cz, and Fz by using t tests of the Fisher z-transformed correlation coefficients. To investigate whether the nature of the relationships was linear or nonlinear, multiple regression analyses with age and square of age used simultaneously as independent variables were performed, and whether square of age gave a significant independent contribution to the total amount of explained variance was investigated.

Results

After the use of cutoff criteria (see below), ANOVAs with three age groups × number of correct responses and three age groups × reaction time showed no interaction effects. We correlated the number of correct responses to target and mean reaction time with P3b at the midline electrodes within the different age groups. Only two significant correlations were found. In the youngest group, Cz amplitude correlated – .39 with reaction time ($p < .01$), and in the oldest group Pz latency correlated .42 with number of correct responses ($p < .05$). We were able to identify certain effects of gender on the amplitude of the P3 s along the midline electrodes, and women tended to have larger amplitude. ANOVAs showed main effects between gender and amplitude of the P3 to target at Cz, $F(1,100) = 7.021, p < .01$, Pz, $F(1,100) = 8.829$, $p < .01$, and Oz, $F(1,100) = 11.019$, $p < .001$), and the same was the case for P3 to distractor at Pz, $F(1,91) = 4.40, p < .05$, and Oz, $F(1,91) = 4.82, p < .05$. None of these interactions diminished when age or IQ were used as covariates. However, because the sample in the current study is well balanced between men and women (45.6 vs. 54.4%), there is no significant relationship between age group and gender, $F(2,100) = 0.75$, n.s., and because the focus of this article is on age effects of the two P3 s in general, further analyses for men and women separately were not performed.

Grand-average ERP curves for P3 to distractor and P3 to target for different age groups are presented in Figures 1 and 2. As can be seen in Figure 1, latency of P3 to distractor is prolonged and the amplitude is reduced at the midline electrodes with increasing age, especially at Cz and Pz. The effect of age is

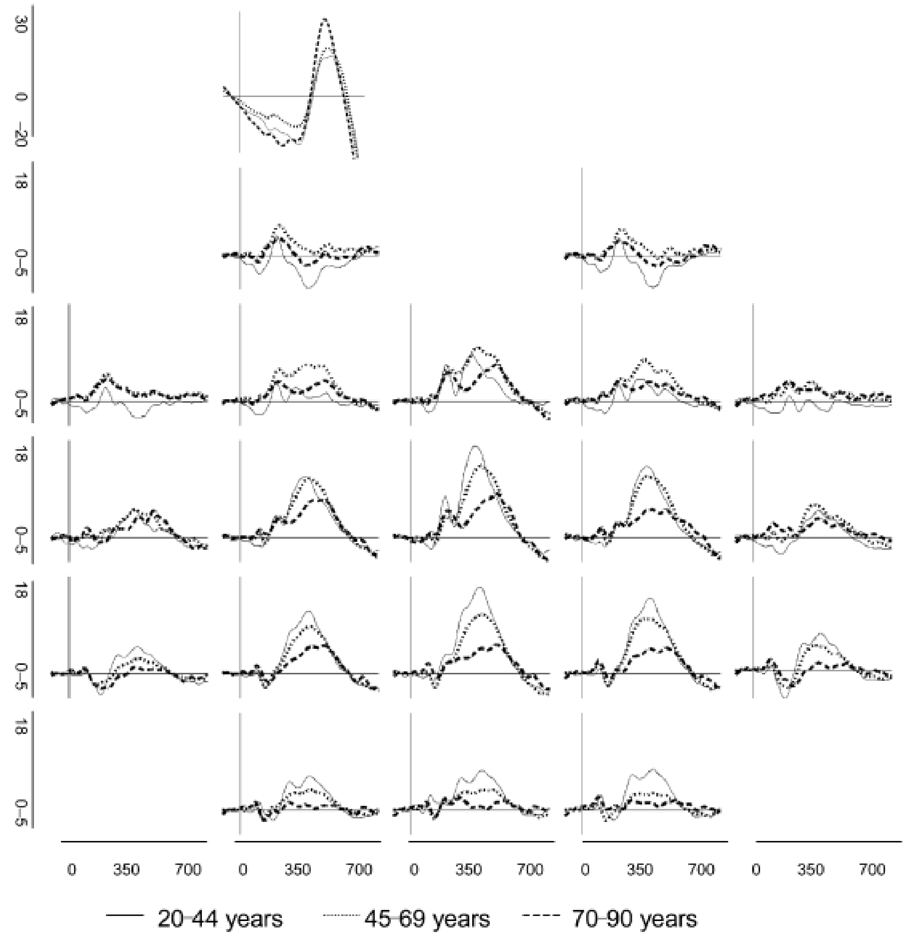


Figure 1. Grand average ERP curves for P3a for 20 electrodes, across three age groups. Microvolts on the y-axis, milliseconds on the x-axis. Row 1: VEOG. Row 2: Fp1, Fp2. Row 3: F7, F3, Fz, F4, F8. Row 4: T3, C3, Cz, C4, T4. Row 5: T5, P3, Pz, P4, T6. Row 6: O1, Oz, O2.

less pronounced at the lateral recording sites, for instance, F7, F8, T3, and T4, and the prefrontal recording sites, Fp1 and Fp2. From Figure 2, it is obvious that amplitude of P3 to distractor is stronger than amplitude of P3 to target for the two youngest age groups. However, this difference diminishes in the oldest age group (70–90 years old). Mean and standard deviations for P3 to distractor and target at Fz, Cz, and Pz are presented in Table 1.

How Strong Is the Relationship between Age and P3 to Distractor?

Scatterplots illustrating the relationship between age and P3 to distractor and target measured at Cz are presented in Figures 3 and 4. The correlations between age and P3 to distractor and target are presented in Figure 5. For latency of P3 to distractor, 14 of 20 correlations were significant ($p < .05$), with Cz reaching an r value of .53. Eight of these still were significant after the Bonferroni correction ($p < .0025$). For amplitude, 11 of 20 correlations reached statistical significance, the strongest correlation being $-.52$ (Pz). The Bonferroni correction rendered 7 of these significant at the adjusted level of probability. P3 to target showed surprisingly low correlations with age, with only three significant correlations for latency and three for amplitude. Of these, only latency at T5 correlated significantly with age after the Bonferroni correction.

At Which Recording Sites Is the Relationship between P3 to Distractor and Age Strongest?

The amplitude and latency for each age group along the midline electrodes Fz, Cz, and Pz are shown in Figure 6. ANOVA with three age groups × electrodes (Fz, Cz, Pz) showed significant interaction effects of age on the topography of P3 along the midline for distractor amplitude, Greenhouse–Geisser $F(184,824) = 9.625$, $p < .000$, and a significant main effect of age group, $F(2,100) = 11.061$, $p < .000$. There was no Age Group × Electrode interaction effect for latency, Greenhouse–Geisser $F(3,329) = 0.333$, n.s., but a main effect of age group, $F(2,100) = 27.294$, $p < .000$. As can be seen from Figure 5, the strongest correlations were obtained at the midline (Fz, Cz, Pz) and central electrodes (C3, C4). The correlations were stronger at parietal than at frontal recording sites. Generally, the strongest amplitude correlations were somewhat more posteriorly distributed than the latency correlations. T tests of Fisher z-transformed correlation coefficients showed that amplitude was significantly less correlated with age at Fz than at Cz, $t = 2.770$, $p < .01$, and Pz, $t = 3.580$, $p < .02$, whereas no significant difference was found between the age correlations at Cz and Pz, $t = 0.773$, n.s. For amplitude of P3 to target, the commonly observed frontal shift was identified. The strongest correlations between amplitude and age were found at Cz and Pz. The Fz correlation was

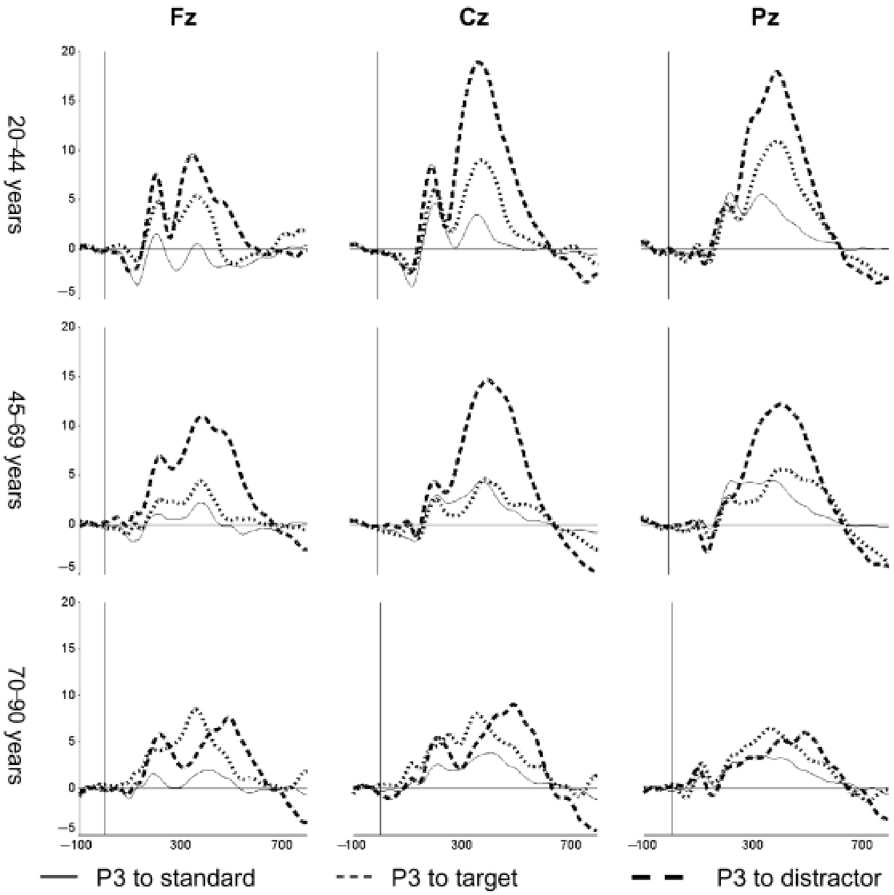


Figure 2. Grand average ERP curves for P3 to distractor and P3 to target for each age group. Microvolts on the y-axis, milliseconds on the x-axis.

significantly smaller than the Cz, $t = 2.027$, $p < .05$, or Pz, $t = 2.104$, $p < .05$, correlations, whereas no significant difference existed between Cz and Pz, $t = 0.074$, n.s. In addition, two positive correlations were identified at F7 and F8. For latency of P3 to target, the strongest relationships were identified at T5, T6, and P3.

Is P3 to Distractor and Age Related in a Linear or Nonlinear Fashion?

The tests for curvilinearity yielded only one significant result, latency of P3 to distractor at T6 ($y = 402.72 - 3.02x + 0.05x^2$, $p < .05$). In this case, R squared increased from 24 to 28%.

Discussion

How Sensitive Is P3 to Distractor to Age?

P3 to distractor seems moderately sensitive to age, yielding an explained variance of about 30% at most. Both latency and amplitude measures are moderately correlated with age, indicating that diminished attention orienting may be a part of cognitive decline observed in normal aging. The correlations are comparable to those reported by Walhovd and Fjell (2001) with an auditory paradigm and a small, polarized sample. The age-related decline in latency seems to be slightly stronger than what

Table 1. *Mean and Standard Deviations for P3 to Distractor (P3a) and P3 to Target (P3b) at Fz, Cz, and Pz*

	Parameter	Stimuli	20–44 years, mean (*SD*)	45–9 years, mean (*SD*)	70–90 years, mean (*SD*)	F^a	*p*
Fz	amplitude	distractor	12.4 (5.8)	13.1 (6.5)	10.4 (5.4)	1.6	n. s.
Cz	amplitude	distractor	21.1 (8.4)	17.1 (6.8)	12.5 (6.6)	10.8	<.000
Pz	amplitude	distractor	19.4 (7.1)	15.2 (6.3)	9.8 (5.6)	18.0	<.000
Fz	amplitude	target	8.1 (5.0)	6.4 (5.1)	9.7 (5.8)	3.0	=.055
Cz	amplitude	target	10.8 (6.5)	7.0 (4.8)	10.2 (8.3)	3.2	<.05
Pz	amplitude	target	12.5 (6.9)	7.9 (3.9)	10.3 (6.8)	5.3	<.01
Fz	latency	distractor	370 (74)	406 (71)	448 (69)	9.9	<.000
Cz	latency	distractor	371 (48)	419 (44)	453 (71)	21.0	<.000
Pz	latency	distractor	372 (45)	402 (51)	456 (101)	13.9	<.000
Fz	latency	target	387 (97)	412 (107)	384 (55)	0.9	n. s.
Cz	latency	target	394 (70)	426 (86)	392 (66)	2.0	n. s.
Pz	latency	target	390 (55)	435 (82)	397 (84)	3.9	<.05

[a] Main effect of age (three groups) on electrode.

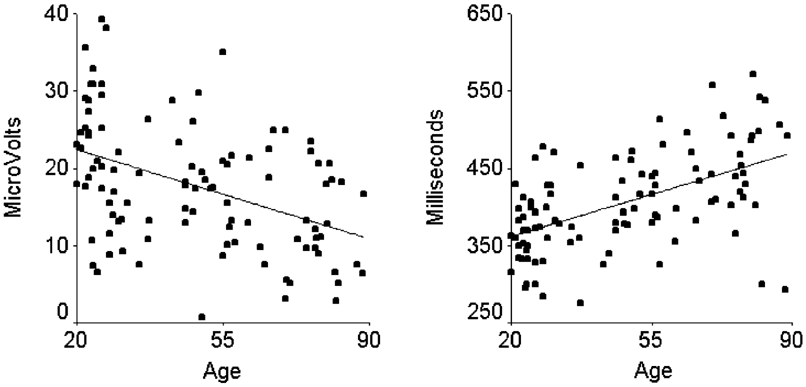


Figure 3. Regression plots for P3 amplitude to distractor ($y = 25.7 - 0.2x$, $p < .000$) and P3 latency to distractors ($y = 330.9 + 1.6x$, $p < .000$) at Cz and age. Only one relationship (T6 latency) was best described by introducing a nonlinear component.

is previously reported for visual P3 to target. The slope in the present study of an increase in latency of 1.6 ms per year is steeper than in the seven visual P3b studies reviewed by Polich (1996), although the differences are small. The strongest correlation between age and latency in the present study ($r = .53$) almost perfectly matches the median correlation from Polich (1996; $r = .54$). Regarding amplitude, the slope of 0.2 μV observed in the present study mimics the results from Picton et al. (1984), but seems to be somewhat stronger than what was reported by Polich (1997). In sum, P3 to distractor seems to be related to age as strongly as or more strongly than what has previously been reported for P3 to target. Thus, age variations in normal, healthy individuals are to a substantial degree captured by electrophysiological measures.

P3 to target was also easily identifiable, but low correlations with age were found. This can partly be explained by the task employed, designed to maximize P3 to distractor on behalf of P3 to target. No previous studies report how the age–P3 to target relationship is affected by introducing a distractor into the string of standard and target stimuli. In the present study it seems that P3 to visual targets is less sensitive to normal life-span changes when a third, nontarget stimulus is introduced.

As a conclusion, P3 to distractor in this paradigm clearly is diminished with age, compared to P3 to target, which was less susceptible to age changes. This may also be the explanation for the delay of the latency of P3 to distractor relative to target in the oldest group. Thus, the present results, particularly at Cz, are to some degree analogous to Knight's (1984), and in accordance with cognitive theories of aging focusing on selective frontal decline. Still, the alternative hypothesis, that older people are better at focusing attention and avoiding distractions than younger people, and thus have a smaller P3 to distractors, cannot be rejected. However, the latter explanation is less in line with evidence of neuroanatomical frontal lobe changes with age (for a description of prefrontal structural changes with age, see, e.g., DeCarli et al., 1994; Raz et al., 1997; Salat, Kaye, & Janowsky, 2001).

At Which Recording Sites Is the Relationship between P3 to Distractor and Age Strongest?

As predicted, P3 to distractor was most strongly related to age at midline electrodes. The component is most pronounced at these recording sites, and so it seems that the activity in the neural generators responsible for producing P3 to distractor is best observed near the midline. As the MANOVAs showed, a main interaction effect of age group × electrode exists for distractor amplitude and latency, and target amplitude. No previous studies have investigated the topographical distribution in P3 to distractor as a function of age with a large, life-span sample. Figures 1 and 2 show that the three age groups exhibit largely the same topographical pattern, but that the frontal activity in the oldest and the middle-aged group seems to be enlarged relative to the young group. Thus, the frontal shift commonly observed in P3b seems to be present also for the P3 to distractor, the so-called P3a.

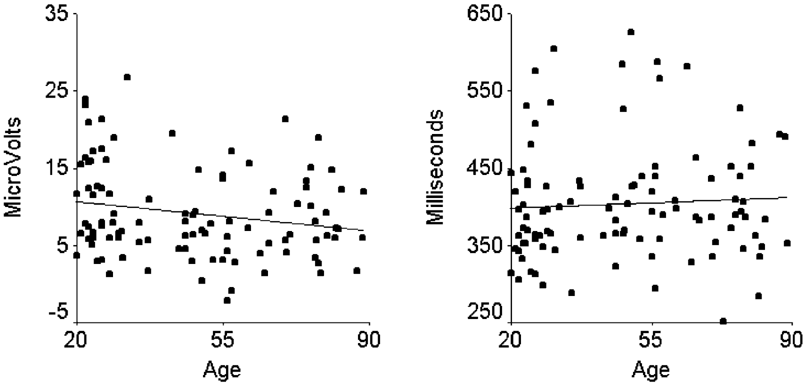
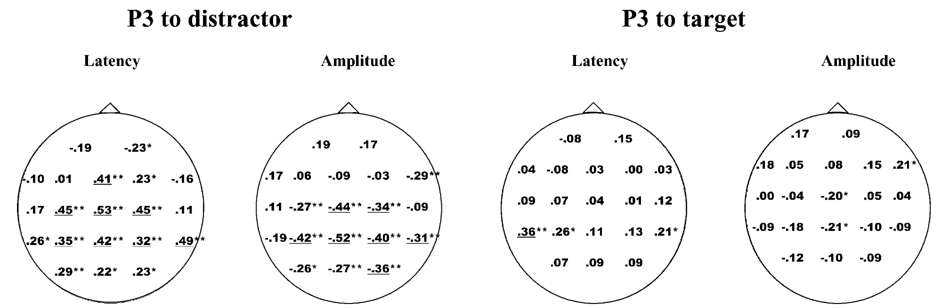


Figure 4. Regression plots for P3 amplitude to target ($y = 11.8 - 0.5x$, $p < .05$) and P3 latency to target ($y = 394.2 + 0.2x$, n.s.) at Cz and age. No relationship was best described by introducing a nonlinear component.



* p < .05 ** p < .01 Underlined: Bonferroni corrected probability levels (p < .0025)

Figure 5. Pearson correlations between P3 latency and amplitude to distractor/target for 20 electrodes and age.

Due to the above described frontal shift in P3 to target, age and amplitude are commonly less strongly correlated at the frontal electrodes. As mentioned, this seems to be the case also for P3 to distractor, which is much less related to age at Fz than at Cz and other more posterior recording sites. This aspect of the present results is not analogous with Knight's (1984) finding that P3a at Fz was reduced in frontal injury patients. In this regard, the present findings fit better with Kaipio et al.'s (1999), and may be interpreted as a relative increase in amplitude of P3 to distractor with increased distractibility with age, especially at frontal recording sites. However, taking the relationship between P3 to distractor and P3 to target into account, the picture is less clear. The amplitude of P3 to distractor is much greater than the amplitude of P3 to target for the youngest participants, but not for the oldest. If P3 to distractor reflects disinhibition and distractibility, one would not expect such a relative reduction of amplitude of P3 to distractor versus amplitude of P3 to target. We need a better understanding of the relationship between P3 to distractor and P3 to target to be able to integrate the results from studies with different paradigms, using different populations of patients and normal participants.

Is P3 to Distractor and Age Related in a Linear or Nonlinear Fashion?

It is clear from our data that age and P3a are related in a linear fashion. The implication is that the age-related change of frontal lobe function is steady with no sudden breaks. This pattern makes the P3 to distractor a potentially valuable tool in detecting pathological changes in frontal lobe function, for instance, in head injuries or degenerative diseases such as frontal lobe dementia. Generalizing from our cross-sectional data, acceleration of prolongation of the latency or acceleration of reduction of amplitude thus seems abnormal.

The Relationship between P3 to Distractor and P3 to Target

The P3 to distractor in the present study has maximum amplitude at Cz, which is expected based on the findings from Courchesne (1978) and Courchesne et al. (1978), as well as Comerchero and Polich (1998, 1999). Inspections of the amplitude graphs reveal an increase in amplitude from Fz to Cz and a reduction of amplitude to Pz. This is in contrast to P3 from target, which shows a slight increase from Fz through Cz to Pz, or an even distribution of activity. Thus, the distractor stimulus causes an

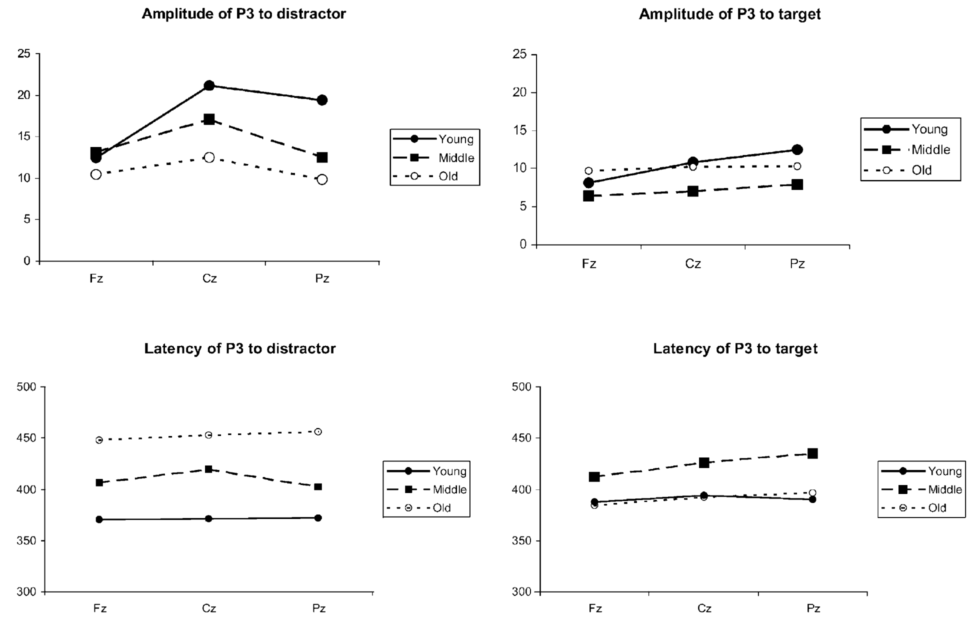


Figure 6. Mean latency and amplitude for each age group for Fz, Cz, and Pz. Amplitude/latency on the y-axis, and electrode on the x-axis. For P3 to distractors, ANOVAs showed significant main effects of age group on amplitude and latency, and a significant Age Group × Electrode interaction effect. No significant effects were found for P3 to target.

anterior shift in amplitude relative to the target stimulus. The topography of the two P3 components in the present study is therefore not different from what one would expect from P3a and P3b, respectively.

The amplitude of P3 to distractor is larger than amplitude of P3 to target. Comerchero and Polich (1999) found this to be the case in an auditory task where the difference between target and distractor was large, but not in a visual task. Still, one might speculate that the target–distractor difference in the present study is even more salient than in Comerchero and Polich's (1998) study. In the latter study, the areas covered by the target and distractor both were 12.57 cm^2, and the discrimination was made on the bases of form (circle vs. square) and color (blue vs. fuchsia). In the present study, the area covered by the distractor is nearly double the area covered by the target. Thus, it is likely that the distractor stimulus in the present study is more attention grabbing, and thus to a larger extent activates automatic alerting responses thought to be responsible for the generation of P3a. This may have led to an increase in P3 amplitude at all recording sites, and thus accounts for the elevation of P3 distractor amplitude relative to P3 target amplitude in the present study.

Conclusion

Visual P3 to distractor seems selectively susceptible to age processes relative to visual P3 to target. This may be seen as supporting cognitive theories of aging postulating selective decline of frontal function with age. However, the age-dependent impairment of P3 to distractor seems less pronounced at frontal than at central or posterior recording sites. Although the latter may be interpreted as an increased "frontally based" distractibility or disinhibition response, the two findings are problematic to integrate in a straightforward account of age changes in frontal function. There is a need for complex theoretical integration of these and previous findings. The relationship between P3 to distractor and aging seems to be of a linear nature, indicating that the cognitive functions indexed by the component are changing in a gradual and steady manner across the whole adult life span.

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