Psychophysiology, 35 (1998), 508–520. Cambridge University Press. Printed in the USA.

Effects of aging on the novelty P3 during attend and ignore oddball tasks

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Abstract

The effects of attention were assessed on novelty P3 amplitude and scalp distribution elicited by environmental sounds in young and elderly volunteers who participated in either actively attended or ignored oddball conditions. For the young, novelty P3 amplitude decreased with time on task during both attend and ignore sequences. Amplitude decrements were greatest at frontal sites during the attend condition, but at all sites during the ignore condition. A reliable amplitude decrement was not observed for the elderly in either the attend or ignore oddball series. The data suggest that attention differentially activates multiple generators that contribute to scalp-recorded novelty P3 activity. The lack of novelty P3 habituation seen in the elderly is consistent with changes in frontal lobe function as age increases.

Descriptors: Novelty P3, Aging, Frontal lobes, Oddball task

Several varieties of P3 waves have been recorded in response to infrequently occurring stimuli embedded in oddball tasks that have different task requirements. For example, the "P3a" (with a latency to peak of about 280 ms), first recorded by Squires, Squires, and Hillyard (1975), was elicited in response to highly infrequent, repetitive, background tones that the subject ignored, and had its maximum amplitude at a central midline scalp site (i.e., Cz). By contrast, the "P3b," synonymous with the well-known P3 or P300 component first discovered by Sutton, Braren, Zubin, and John (1965), is elicited by attended, task-relevant, infrequent events (see Donchin & Coles, 1988, and Johnson, 1986, for reviews). The P3b reaches peak latency between 300 and 1000 ms poststimulus (depending on the complexity of the task and clinical sample), and its scalp distribution is usually, but not always, characterized by a maximum at parietal electrode sites (again depending on task and clinical sample).

The P3 elicited by infrequent, task-irrelevant novel events (novelty P3), about which the subject is not informed at the beginning of the experiment, has a more frontally oriented scalp distribution than the P3b, and a latency to peak of about 320 ms (e.g., Courchesne, Hillyard, & Galambos, 1975; Fabiani & Friedman, 1995; Friedman & Simpson, 1994; Knight, 1984). Because it is not at all clear at this stage of our knowledge whether the P3a and the novelty P3 are identical, this activity has been labeled the "novelty P3" (e.g., Fabiani & Friedman, 1995; Friedman, Simpson, & Hamberger, 1993). The novelty P3 was originally discovered in the visual modality (Courchesne et al., 1975), but has since also been observed in response to novel auditory environmental sounds (e.g., Fabiani & Friedman, 1995; Knight, 1984). The novelty P3 is elicited typically under active attention by several, unique environmental sounds. It is assumed to reflect aspects of the orienting response, as it is altered after unilateral dorsolateral prefrontal cortical lesions (Knight, 1984; see Knight, 1996, for evidence of a hippocampal generator), which also lead to disordered orienting (Woods & Knight, 1986).

Habituation of the Novelty P3

Previous studies from this (e.g., Cycowicz, Friedman, & Rothstein, 1996; Friedman & Simpson, 1994) and other (e.g., Courchesne, 1978; Knight, 1984) laboratories have shown that, in young adult participants, the novelty P3 "habituates." Habituation of this component has been demonstrated in several ways: (a) by averaging the event-related potentials (ERPs) elicited by several unique novel sounds within a block of trials and then assessing the extent of amplitude decrement across the series of blocks (labeled block number by Friedman & Simpson, 1994); (b) by averaging the ERPs to several unique environmental sounds, some of which repeat at a subsequent point in the stimulus sequence and then measuring the magnitude of amplitude reduction from the first to the second presentation (Cycowicz et al., 1996), as in repetition priming experiments (e.g., Friedman, Hamberger, & Ritter, 1993); (c) by averaging the ERPs to several unique environmental sounds according to their numerical appearance, relative to other novel events, within a block of trials. The extent of amplitude reduction

This study was supported in part by grants AG05213 and AG09988 from the National Institutes on Aging, and by the New York State Department of Mental Hygiene.

We thank Charles L. Brown III for computer programming and technical assistance, Jeff Cheng and Sean Hewitt for aid with data collection, and Rachel Yarmolinski and Eve Vaag for art work and photo reproduction. Many thanks to Dr. Donald Ross for providing statistical advice. We thank all of the participants for generously giving their time.

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from the first to the last novel event (labeled serial order by Friedman & Simpson, 1994) is then assessed across blocks (i.e., all first novels, all second novels etc.); and (d) by measuring single-trial ERPs to a single, repetitive novel event and assessing amplitude reduction across the entire experiment (Knight, 1984). Hence, two effects appear to modulate novelty P3 amplitude, repetition of the *identical* novel event, and the continual presence or recurrence of *unique* novel stimuli.

The reduction in novelty P3 amplitude has been shown, in several studies, to be greater at frontal than posterior electrode sites (e.g., Courchesne, 1978; Cycowicz & Friedman, 1997; Friedman & Simpson, 1994). Moreover, novel sound repetition and recurrence both elicited a topographic change in the novelty P3 from an amplitude that was initially frontally oriented to one that was more posteriorly oriented as more novels were delivered (e.g., Friedman & Simpson, 1994). These findings, along with source modeling studies (Simpson, Fabiani, & Friedman, submitted), and data based on patients with localized prefrontal brain lesions (Knight, 1984), led Cycowicz and Friedman (1997) to suggest that the brain's response to novelty involves the activation of a neural circuit that reflects the activity of many brain regions that may include both anterior and posterior cortical elements.

Unlike young adults, normally aging older adults did not show similar amplitude reductions and topographic changes with novel repetition and recurrence (e.g., Friedman & Simpson, 1994; Kazmerski & Friedman, 1995). Based on several lines of converging evidence, including Knight's (1984) studies of patients with dorsolateral frontal lobe lesions, studies of age-related neuropathological changes (e.g., Ivy, MacLeod, Petit, & Marcus, 1992), and experimental neuropsychological investigations (e.g., Albert & Kaplan, 1980; Craik, Morris, Morris, & Loewen, 1990; Stuss, Craik, Sayer, Franchi, & Alexander, 1996), Friedman and Fabiani (1995) suggested that the lack of scalp distributional change as a function of repetition and recurrence might be due to a change in frontal lobe function with increasing age.

Motivation for the Current Investigation

The purpose of the current study was to extend these observations to a condition in which the oddball stimuli included novel environmental sounds that were ignored. The study was motivated by the following considerations. Kazmerski, Friedman, and Ritter (1997) and Woods (1992) observed that normally aging older participants produced a similar sequence of mismatch negativity, N2b, and P3 components in response to novel events when those events were unattended or ignored. However, the major focus of those investigations was on the mismatch negativity (Kazmerski et al., 1997; Woods, 1992) and the Nd (Woods, 1992), and not on the novelty P3. Thus, it is unclear whether the effects of repetition and recurrence described above also hold for novel events that are unattended. According to Näätänen's (1992) model, the presence of N2b and P3 components elicited by "ignored" stimuli indicate that those stimuli have attracted attention, as N2b and P3 components are not observed to deviant tones under ignore conditions (Näätänen, 1990; 1992). As the elderly show robust N2bs and P3 components to novel stimuli during attend oddball tasks (e.g., Kazmerski & Friedman, 1995), one question raised here is the extent to which this passive switch mechanism is intact in the elderly under ignore conditions. Thus, it was of interest to determine if the elderly would show habituation of the novelty P3 (as a function of repetition and recurrence) during an ignore oddball condition. As stated earlier, it has been proposed (e.g., Cycowicz & Friedman, 1997; Simpson et al., submitted) that during attend oddball tasks the novelty P3 receives contributions from frontal and posterior cortical generators, but it is unknown to what extent these same generators are activated under ignore instructions. Topographic differences as a function of both age and novel repetition and/or recurrence between the novelty P3 elicited under attend compared to ignore conditions could aid in answering this query.

To answer the questions posed immediately above, the data of Kazmerski et al. (1997) were reanalyzed. Kazmerski et al. (1997) had described the mismatch negativity in patients with Alzheimer's disease to deviant tones (i.e., repeated, non-novel) and novel sounds in attend and ignore oddball conditions. The healthy young and elderly participants whose novelty P3 data were described in this report served as controls. The focus of the current investigation had a different objective. The ERPs to the novel environmental sounds were reaveraged by block to assess the effect of block number on novelty P3 amplitude and scalp distribution. These effects were examined in two independent groups of elderly participants and two independent groups of young adult participants who served under either attend or ignore oddball conditions. The effect of attention was assessed between-subjects to maintain the novelty of the sounds, that is, to preclude additional "habituation" to novelty. Maintaining novelty would have been difficult had attention been manipulated within-subjects as, regardless of whether attend or ignore instructions were administered first, both types of sequences would have been comprised of similar sets of environmental sounds.

METHODS

Participants

Four independent groups of young and elderly participants served in these experiments. One group of young ($n = 16$) and one group of elderly adults ($n = 16$) participated in the attend oddball condition, while the other group of young ($n = 15$) and elderly adults ($n = 14$) participated in the ignore oddball condition (Table 1).[1] Some of the participants were also volunteers in a verbal repetition priming study (Kazmerski & Friedman, 1997), which always preceded the oddball series reported here.[2] For both attend and ignore oddball conditions, young and elderly adults were recruited by notices posted within the Columbia Presbyterian Medical Center community and through advertisements in local newspapers.

Older participants were determined to be free of depression, dementia, and limitations in the activities of daily living as assessed by the Short CARE (Gurland, Golden, Teresi, & Challop, 1984). They were normal on a complete medical and neurological examination, administered by a board-certified neurologist, that assessed prospective participants for the presence of neurodegenerative disorders (e.g., Parkinsonism, cerebellar disease, multiple sclerosis), and clinically detectable neurovascular disease [embolic cerebrovascular accident (CVA), thrombotic CVA, lacunar CVA]. The examination also included an assessment of visual acuity, visual fields, gait, and the presence of any tremor or rheumatolog-

[1]The ERP data from the attend oddball condition for the young and elderly subjects as a function of novel repetition have been detailed previously (Kazmerski & Friedman, 1995).

[2]Of the 15 young volunteers who participated in the ignore condition, 9 had also participated in a repetition priming study immediately prior to the oddball tasks described here; of the 14 elderly adults who participated in the ignore condition, 3 had participated in the repetition priming study; all 16 of the young and elderly subjects who participated in the active version of the oddball task had also been participants in the repetition priming study.

Table 1. *Demographic Characteristics of the Attend and Ignore Young and Elderly Samples*

Group	Age	EDUC	SES	mMMS	VIQ[a]	PIQ[b]	dB level
Attend young (*n* = 16; 8 male, 8 female)	23.9 (2.6)	17.2 (1.7)	51.4 (11.3)	55.5 (1.3)	112.8 (10.9)	109.4 (10.9)	82.4 (3.8)
Attend elderly (*n* = 16; 5 male, 11 female)	69.1 (6.3)	16.0 (2.4)	50.6 (15.7)	54.6 (1.7)	113.2 (9.4)	103.5 (8.4)	91.3 (9.2)
Ignore young (*n* = 15; 4 male, 11 female)	24.3 (3.1)	16.7 (0.8)	56.9 (8.8)	55.7 (1.1)	117.9 (9.6)	110.1 (15.1)	83.5 (3.9)
Ignore elderly (*n* = 14; 2 male, 12 female)	70.3 (5.5)	15.7 (2.9)	51.3 (17.8)	54.9 (1.6)	118.2 (12.7)	110.1 (10.9)	96.6 (7.3)

Note: Values represent mean (SD). EDUC = years of education; SES = socioeconomic status (higher score = lower SES); mMMS = modified Mini-Mental State Examination (Mayeux et al., 1981); VIQ = verbal IQ; PIQ = performance IQ; dB level = dB SPL level at which auditory stimuli were presented.
[a]Estimated from the Vocabulary subtest for the young adults; [b]Estimated from the Block Design subtest for the young adults; for the elderly adults, the verbal and performance IQs are age-corrected.

ical disorders (arthritis; to ensure that they were able to manipulate the response buttons). All young participants reported themselves to be in good health and to have no major medical, neurological, or psychiatric problems. All participants signed informed consent, were native English speakers, and received payment for their participation.

Pure tone audiometry was obtained for all participants. Hearing threshold was tested at 250, 500, 1000, 2000, and 4000 Hz. All participants met the following criteria: no more than a 40-dB mean loss across frequencies, less than a 20-dB difference between ears at each frequency, and less than a 30-dB difference between the best and worst threshold. However, the decibel level at which all stimuli were presented was adjusted for any subject who showed a mean hearing loss greater than 0 dB (averaged across frequencies and ears) by increasing (from 75 dB) the intensity of the stimuli by the mean decibel hearing loss.

A neuropsychological test battery included the modified Mini-Mental State Examination (mMMS; Mayeux, Stern, Rosen, & Leventhal, 1981) and, for the young, the vocabulary and block design subtests of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981), from which their verbal and performance IQ quotients were, respectively, estimated. Older participants received the Satz and Mogel (1962) abbreviated form of the WAIS, modified for the WAIS-R by Adams, Smigielski, and Jenkins (1984). The Edinburgh handedness questionnaire (Oldfield, 1971) was also administered. A socioeconomic status index was obtained based on education level and occupation (Watt, 1976). Participants in the four groups had similar scores on these measures, as seen in Table 1.

Stimuli

Auditory stimuli were pure tones and environmental sounds. The pure tones were 500 Hz (high) and 350 Hz (low), and were presented for a duration of 336 ms (rise and fall times of 10 ms). The novel sounds were 48 unique sounds that formed part of a larger corpus of environmental sounds described in detail by Fabiani, Kazmerski, Cycowicz, and Friedman (1996), and came from four categories: animals, human sounds, musical instruments, and artificial or machine sounds. Their duration varied from 159 to 399 ms (mean = 336 ms, SD = 61). The rise and fall times varied for the novel stimuli based on the nature of the stimuli. Some stimuli tapered on and off naturally (e.g., bird calls). To offset clicking sounds in the stimuli that ended or began abruptly, a ramp of less than 10 ms was added. The novel sounds were matched for peak equivalent sound pressure level (SPL) to the pure tones using a decibel meter. The grand mean decibel SPL levels at which the stimuli were delivered (using the adjustment procedure described above) are presented in Table 1 for each of the four groups of participants.

Procedure

Participants in the attend condition were instructed to press a button (with an emphasis on speed) with the thumb of one hand when they heard the rare oddball tone (i.e., target). Participants in the ignore condition were asked to read self-selected text while ignoring the auditory stimuli presented in the background. No response was required for the volunteers participating in the ignore condition. Subjects were first presented with two blocks of a standard auditory oddball task. In each of these 100-trial blocks, subjects heard the high and low pure tones in random order with an interstimulus interval of 1,000 ms (onset to onset). One tone was presented 88% of the time and designated as the standard, whereas the other tone was presented 12% of the time and designated as the rare oddball tone. Rare oddball tone and hand of response were counterbalanced across subjects within each group.

The standard oddball task was followed immediately by 10 blocks of 80 trials each of a novelty oddball task in which unexpected, novel stimuli (10%) were intermixed with standard (80%) and target (10%) tones. Between blocks there was an approximate 1–2 min break during which subjects relaxed and prepared for the next block of trials. The entire run lasted approximately 20–30 min. Subjects were not informed about the occurrence of the novel stimuli. When subjects asked about the novel stimuli, they were instructed to continue with their assigned task. There were 48 unique novel stimuli, of which 32 were presented twice. Table 2 depicts an example of the sequence for a given subject. As can be seen in the table, in the first two blocks, all novel stimuli were new. In the 3rd through 10th blocks, half of the novel items were new and half were old. Repetition of the novel stimuli occurred two blocks after their initial presentation, such that, for example, the novel stimuli initially presented in the first block were repeated in the third novelty oddball block. The novel stimuli that did not repeat ("unique") comprised four of the novel events in the first two and last two blocks. Thus, of the eight novel stimuli presented

Table 2. *An Example of the Novel Repetition Sequences for a Given Subject*

Block								
1	U1	U2	U3	U4	N1	N2	N3	N4
2	U5	U6	U7	U8	N5	N6	N7	N8
3	R1	R2	R3	R4	N9	N10	N11	N12
4	R5	R6	R7	R8	N13	N14	N15	N16
5	R9	R10	R11	R12	N17	N18	N19	N20
6	R13	R14	R15	R16	N21	N22	N23	N24
7	R17	R18	R19	R20	N25	N26	N27	N28
8	R21	R22	R23	R24	N29	N30	N31	N32
9	R25	R26	R27	R28	U9	U10	U11	U12
10	R29	R30	R31	R32	U13	U14	U15	U16

Note: U = unique (not repeated); N = new (first presentation); R = repeat; Within a block the stimuli were presented in random order. They are presented in order in the table for expository purposes only.

in each of Blocks 1 and 2, four were to be repeated ("novel 1") and four were unique. In Blocks 3–8, four novels were new ("novel 1") and four were repetitions ("novel 2"). In the last two blocks, four were repetitions ("novel 2") and four were unique. Of the eight novel stimuli in each block, two were from each of the four different sound categories listed earlier. The novel events that repeated were rotated across blocks for participants within a group. The stimuli were presented in a different random order for each subject with the restriction that a novel or target could not be the first or last stimulus and two novels or targets could not be sequentially presented.

Electroencephalogram (EEG) Recording

EEG was recorded continuously using an Electrocap with placements at Fz, Cz, Pz, F3, F7, C3, P3, T5, F4, F8, C4, P4, T6, and right and left mastoids. All leads, including the mastoids, were referred to nosetip. Vertical electrooculogram (EOG) was recorded bipolarly from electrodes placed on the supraorbital and infraorbital ridges of the right eye, and horizontal EOG was recorded bipolarly from electrodes placed on the outer canthi of the two eyes. The EEG and the EOG were recorded with a bandpass of 0.01–30 Hz, with a time constant of 5.3 s and a sampling rate of 200 Hz. Trials containing eye movement artifact were corrected off-line using the procedure developed by Gratton, Coles, and Donchin (1983). Trials were epoched off-line with 100 ms pre- and 900 ms poststimulus periods.

Data Analyses

As the focus of this study is on the novelty P3, only the data from the novelty oddball blocks are detailed here. Averages of ERPs elicited by novels were computed as a function of block number (1–10).[3] To increase the signal-to-noise ratio, the averages were collapsed across each successive two blocks of trials. That is, the single trials from blocks 1 and 2 were averaged together resulting in a maximum of 16 trials for each of these averages. This resulted in 5 averages per subject (Blocks 1 and 2, Blocks 3 and 4, Blocks 5 and 6, Blocks 7 and 8, Blocks 9 and 10; hereafter referred to as block number).

To compare P3 scalp distributions between groups and/or conditions (e.g., Blocks 1 and 2 vs. Blocks 9 and 10), the data were normalized using the root mean square method described by McCarthy and Wood (1985). This manipulation removes overall amplitude differences between conditions or groups to allow a comparison of the shape of the distribution across the scalp. A significant difference in scalp distribution is revealed as an interaction of a variable with electrode location, for example, significant Electrode Location × Block Number interactions in the current context. Separate normalizations were performed for each age group.

Analyses of variance (ANOVA) were performed using the BMDP-4V Program (Dixon, 1987). These included tests for trend of the within and across block temporal sequences. The Greenhouse–Geisser epsilon correction factor, ϵ (Jennings & Wood, 1976), was used where appropriate. Uncorrected degrees of freedom are reported below along with the epsilon value; the p values reflect the epsilon correction. Where appropriate, significant main effects and interactions were followed-up with simple effects procedures and/or post hoc analyses using the Tukey honestly significant difference (HSD) test. Because of previous findings with the novelty oddball paradigm from this laboratory (e.g., Cycowicz et al., 1996; Kazmerski & Friedman, 1995), it was predicted a priori that the young would show decrements in novelty P3 amplitude as a function of Block Number, but that the old would show these amplitude changes to a much smaller extent, or not at all. Furthermore, it was also predicted a priori, at least for the young, that the novelty P3 amplitude changes as a function of block number would be greater at frontal compared with posterior electrode sites. Hence, (a) ANOVAs were performed separately on the young and old novelty P3 data (in follow-up of the overall ANOVA in which age group was a factor); and (b) simple effects tests were performed separately for each age group to assess whether the effect of block number on novelty P3 amplitude differed for locations along the anterior/posterior dimension of the scalp and for the attend and ignore oddball conditions.

RESULTS

The effects of repetition and recurrence were investigated by averaging the ERPs to novel events as a function of block number (i.e., Blocks 1 and 2, Blocks 3 and 4, etc.). Because of a priori expectations (see above) concerning age-related changes in the anterior versus posterior aspects of the novelty P3 as a function of block number, the scalp sites were grouped into an anterior/posterior dimension (labeled caudality). The experimental design thus had two between-subjects variables, age group (young/old) and attention (attend/ignore) and three within-subjects variables, block number, hemisphere (left/right) and caudality (F3/4, F7/8, C3/4, T5/6, P3/4).

ERP Waveforms

Figures 1 and 2 depict, respectively, the effect of block number on the grand mean averaged waveforms at all 13 scalp sites for the young and elderly during the attend and ignore oddball conditions. There are several noteworthy phenomena evident in these figures: (a) The ERPs elicited by the novels during the ignore series were comprised of N2b and P3 components as were the ERPs to novels during the attend blocks; these components are indicative of active attention (Näätänen, 1992), demonstrating that for both young and old during the ignore condition, the novel sounds captured atten-

[3]Novelty P3 amplitude was also examined as a function of the numerical sequence of novel events within the block of trials (serial order). However, the effect of serial order on novelty P3 amplitude was not nearly as dramatic as that for block number, although it was consistent with previous studies in this series of investigations (e.g., Friedman & Simpson, 1994; Kazmerski & Friedman, 1995). Therefore, these data are not presented.

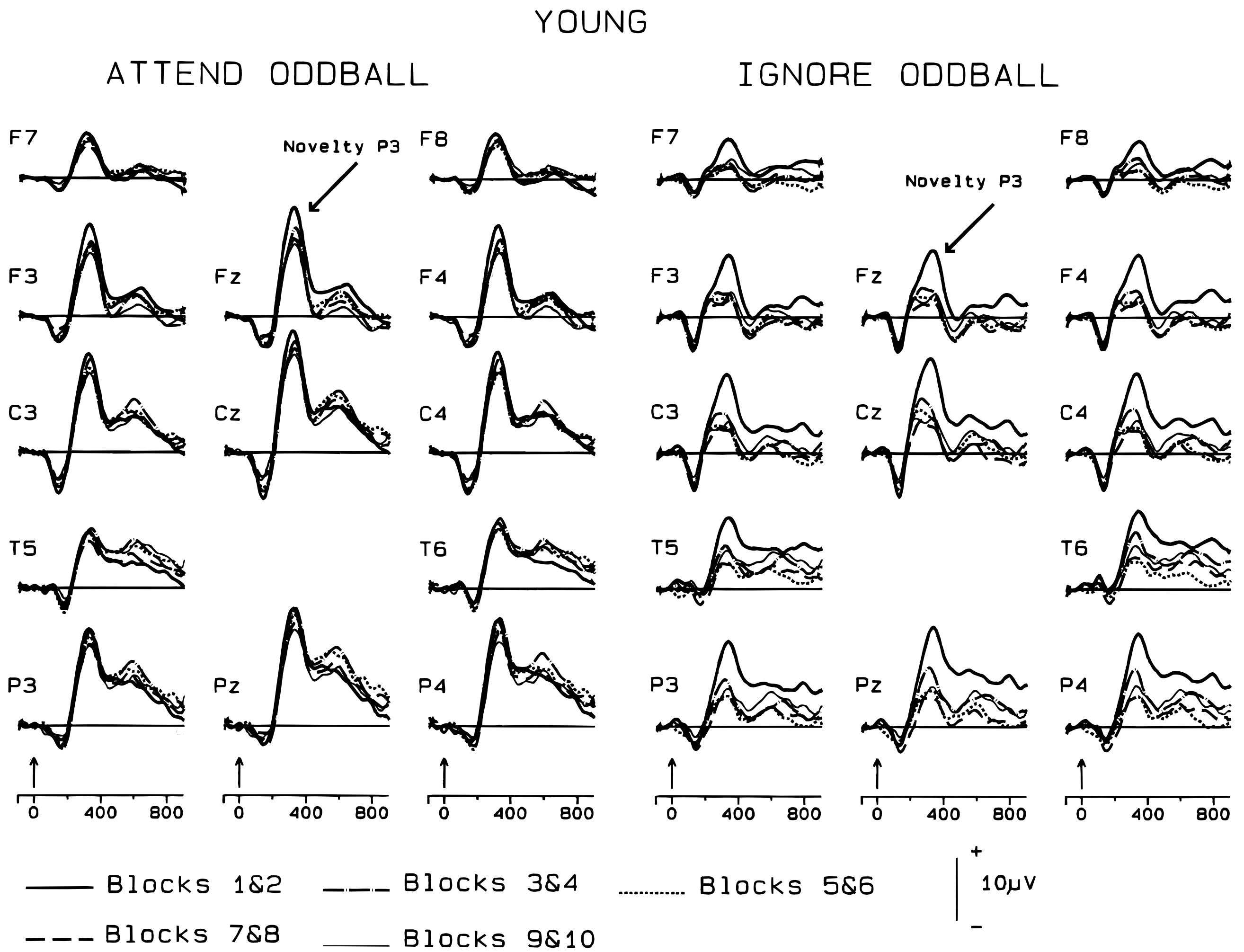

Figure 1. Grand mean event-related potential (ERP) waveforms for the young age groups for the attend and ignore oddball series at all 13 electrode sites. The effect of block number is depicted. Arrows mark stimulus onset with time lines every 200 ms. ERPs elicited by novels in Blocks 1 and 2 (solid heavy line), Blocks 3 and 4 (long dashed and dotted line), Blocks 5 and 6 (dotted line), Blocks 7 and 8 (long dashed line), and Blocks 9 and 10 (thin solid line) are depicted.

tion. (b) For the young, the first positivity, the novelty P3, had a central maximum scalp distribution in both attend and ignore conditions. (c) For the elderly, during attend blocks, the novelty P3 displayed its smallest amplitude at the Cz site, and was equipotential at Fz and Pz. During ignore conditions, by contrast, maximum amplitude was shown at Pz. (d) For the young, the greatest effect of block number appeared to be at the frontal electrode sites during attend blocks, whereas during the ignore condition, all sites showed a dramatic reduction in amplitude with block number. (e) For the elderly, there appeared to be a slight reduction in novelty P3 amplitude only during the ignore condition.

To enable better visualization of these differential anterior and posterior effects, Figure 3 depicts the same conditions as Figures 1 and 2 at frontal (Fz) and posterior (Pz) midline locations only. As can be seen, there was a greater effect of block number for the young at the frontal than at the parietal site during the attend condition. By contrast with the attend condition, the effect of block number for the ignore condition appeared to be greater and was present to the same extent at both frontal and posterior locations. For the elderly, there appeared to be no clear effect of block number during the attend series, whereas there appeared to be a small effect of block number on the waveforms elicited during the ignore series.

For comparison, Figure 4 depicts the ERPs elicited by the rare oddball tones and standards during both attend and ignore novelty oddball blocks. By contrast to the ERPs elicited by rare oddball tones and novel deviants during the attend condition and to the ERPs to the novels during the ignore condition, for both age groups the ERPs elicited by the rare oddball tones during the ignore series did not show the presence of N2b or P3 components, suggesting that, unlike the novel sounds, these tonal stimuli did not capture attention.

Data Analyses

Averaged voltage measures for the novelty P3 were computed with respect to the prestimulus baseline. The latency windows used for young and elderly were, respectively, 240–360 ms and 280–445 ms. Analyses of the midline and lateral scalp site data were performed. However, the midline analyses produced results highly similar to those reported in the ANOVAs below that included the factors of hemisphere and caudality. Thus, they will not be described further.

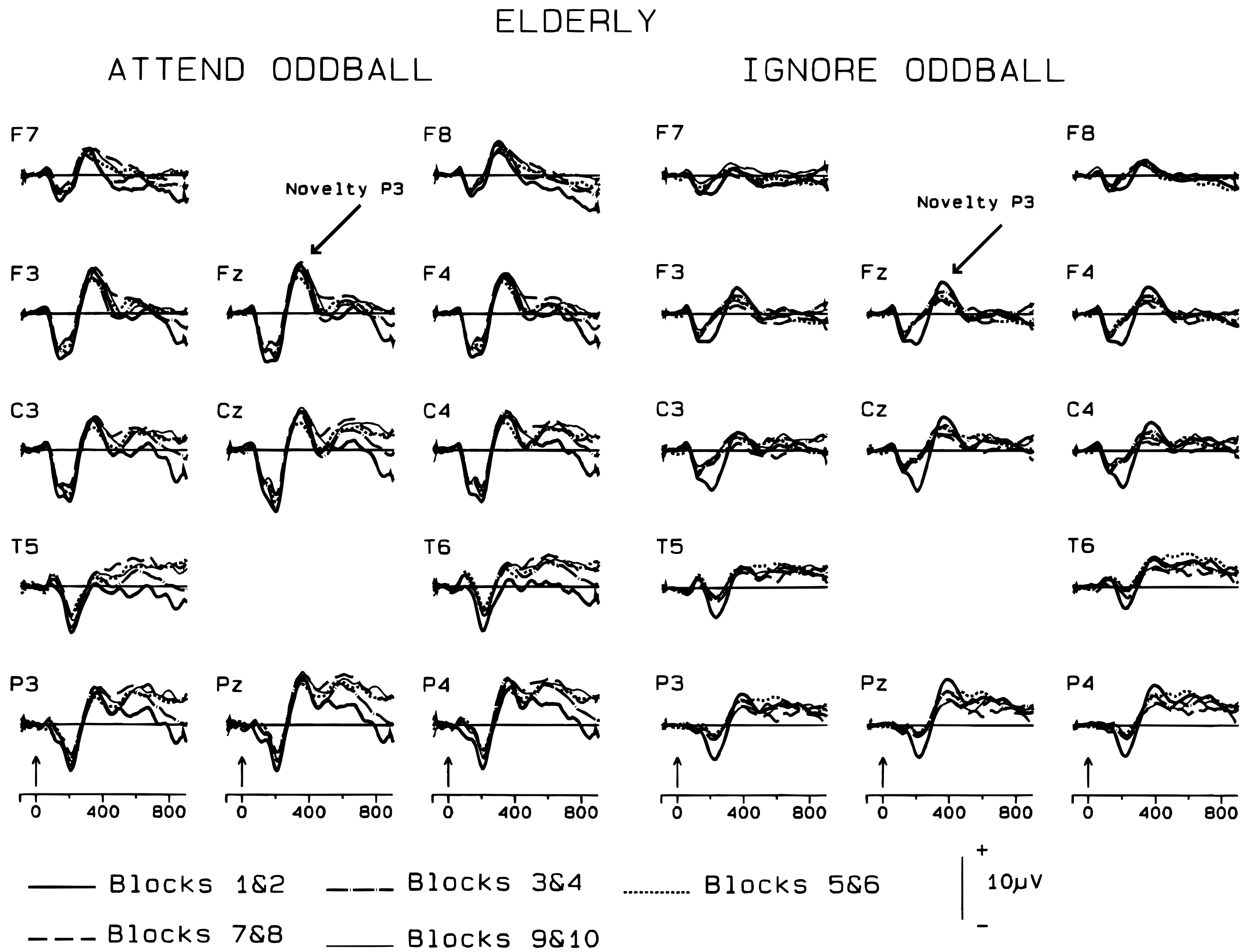

Figure 2. Grand mean event-related potential (ERP) waveforms for the elderly age groups for the attend and ignore oddball series at all 13 electrode sites. The effect of block number is depicted. Arrows mark stimulus onset with time lines every 200 ms. ERPs elicited by novels in Blocks 1 and 2 (solid heavy line), Blocks 3 and 4 (long dashed and dotted line), Blocks 5 and 6 (dotted line), Blocks 7 and 8 (long dashed line), and Blocks 9 and 10 (thin solid line) are depicted.

Raw Amplitude Analyses[4]

The effect of block number on novelty P3 amplitude was first assessed in an ANOVA with two between-subjects factors, age group (young/old) and attention (attend/ignore), and three within-subjects factors, block number (five levels), hemisphere (left/right) and caudality (F34, F78, C34, T56, P34). As can be seen by inspection of Figures 1 and 2, and as corroborated by the ANOVA, the young produced larger amplitudes than the elderly, $F(1,57) = 16.75$, $p < .0001$. More important, young and old differed in the degree of amplitude reduction induced by block number. This finding was shown clearly by the interactions of the trend components with age, linear trend by age $F(1,57) = 11.49$, $p < .001$; quadratic trend by age, $F(1,57) = 5.66$, $p < .02$.

This overall ANOVA was followed up by separate ANOVAs for the young and elderly that are presented in Table 3.[5] The averaged voltage indices corresponding to these ANOVAs are graphically depicted in Figure 5, which shows the effect of block number at each of the five anterior to posterior locations on the scalp for each age group and oddball condition.

Young. As can be seen in Figure 1 and Table 3, for the young (left portion of Table 3), larger novelty P3s were elicited during the attend task. There were significant linear and quadratic trend components with, as can be seen by inspection of Figure 5, the linear trend interacting marginally ($<.07$) with the attention (i.e., attend/

[4]The mean number of sweeps entering into the block number averages varied from 13.8 to 14.4 (range = 5–16) and did not differ as a function of age group, attention (attend/ignore), or block number (Fs < 1.96, ps $>$ .10). The signal-to-noise ratios for all conditions were quite good, and for each individual's set of waveforms the novelty P3 could be easily identified.

[5]Similar ANOVAs (performed separately on the data of the young and the old) on the P3 amplitudes elicited by target tones as a function of block number failed to reveal any significant linear, quadratic, or cubic trends, main effects of block number, or interactions of the trend components with the main effect. These analyses were performed only on the attend data, as there was no evidence of P3 components elicited by the ignored tonal deviants (see Figure 4).

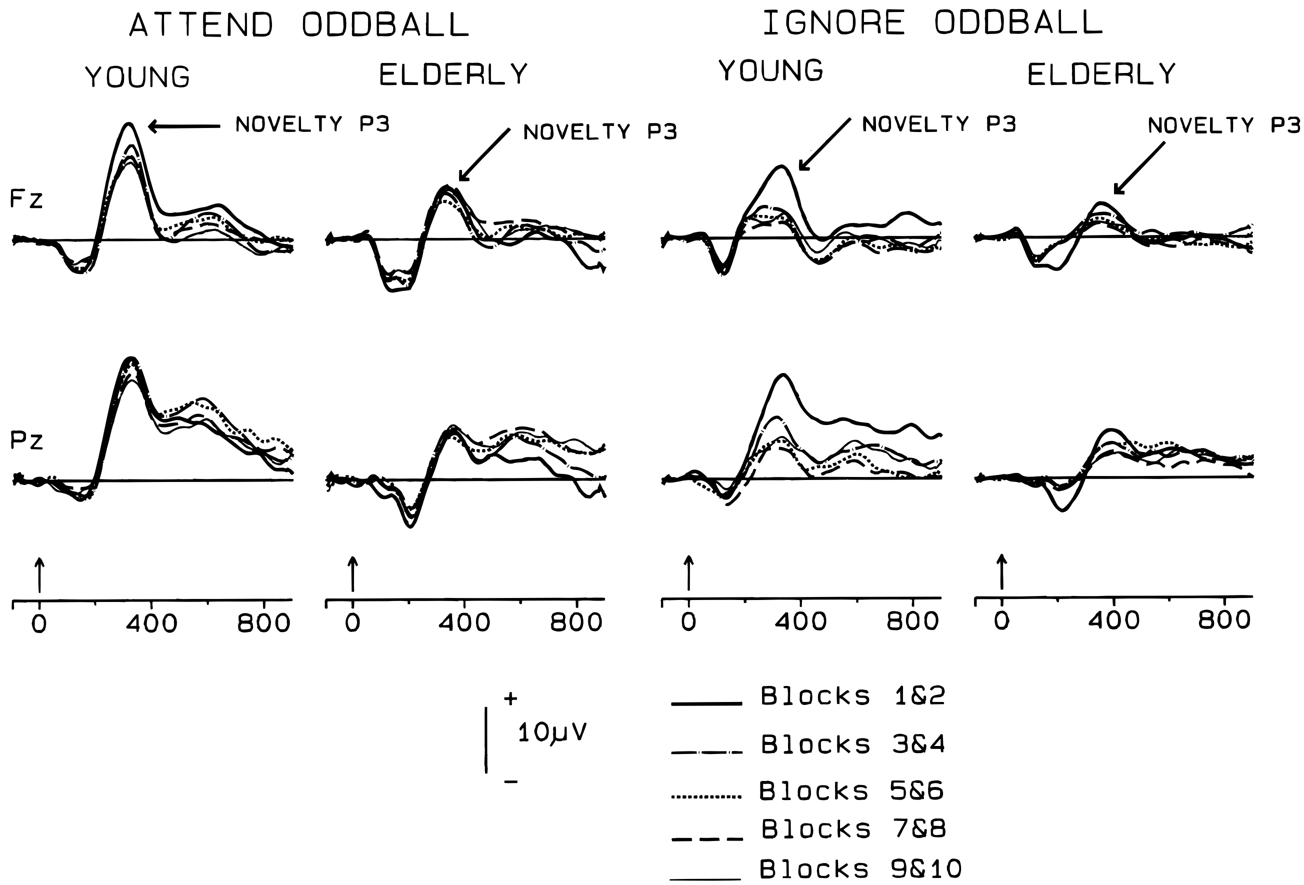

Figure 3. Grand mean event-related potential (ERP) waveforms for each age group and oddball series at midline frontal and parietal locations depicting the same effects as shown in Figures 1 and 2. Arrows mark stimulus onset with time lines every 200 ms. ERPs elicited by novels in Blocks 1 and 2 (solid heavy line), Blocks 3 and 4 (long dashed and dotted line), Blocks 5 and 6 (dotted line), Blocks 7 and 8 (long dashed line), and Blocks 9 and 10 (thin solid line) are depicted.

ignore) dimension. The significant linear trend reflected the overall decrease in amplitude with block number, whereas the interaction reflected a steeper decrease for the ignore oddball task. The linear trend interacted with the caudality factor, indicating that, across attend and ignore conditions, the decrease with Block number differed for the various anterior to posterior locations. The triple interaction of quadratic trend by caudality and attention ($<.07$) was marginally significant. As is evident in Figure 5, this interaction reflected the overall steeper block number functions for all of the scalp locations during the ignore condition, which were smaller and only appeared to occur for the frontal locations (F34) during the attend oddball blocks. Based on our a priori predictions, simple effects of block number at each of the five anterior to posterior scalp locations were performed separately for the attend and ignore oddball sequences (collapsed across hemisphere as no interactions with hemisphere were evident). These calculations revealed that, whereas only the frontal locations (F34) showed significant effects of block number for the attend data, all five of the anterior/posterior locations showed this effect for the ignore data, as is clearly evident in Figure 5.

The Attention $\times$ Caudality interaction suggests that the amplitude differences between attend and ignore conditions is different at the different anterior to posterior locations. Post hoc testing indicated that, except for T56, the novelty P3 under ignore conditions was smaller than its attend counterpart at the remaining four anterior/posterior locations (ps $< .05$). These latter interaction effects are consistent with differential effects of block number and attention on the generator configuration of the novelty P3 (see Analysis of Scalp Topography below).

Elderly. In contrast with the data of the young, fewer main and interaction effects were reliable for the older participants (Table 3; right portion). Unlike the young, novelty P3 amplitudes did not differ between attend and ignore oddball conditions, and the main effect of attention did not interact with the Caudality factor. Moreover, none of the trend components was significant, although both the linear and quadratic trends interacted with the Caudality factor. Based on our a priori predictions, simple effects comparisons assessing the effect of block number at each of the five scalp regions for each type of oddball condition were performed. None of these was significant in the data of the older participants. The older adults' novelty P3 was significantly larger over the right (3.1 μV) than the left (2.4 μV) hemiscalp. The young showed a similar tendency (left = 6.9 μV; right = 7.3 μV) but, as seen in Table 3, this difference was not reliable.

The influence of repetition on the block number function. Because of the way in which the data were averaged (i.e., across successive two blocks of trials), it is possible that the decrement in amplitude as a function of block number may have been exagger-

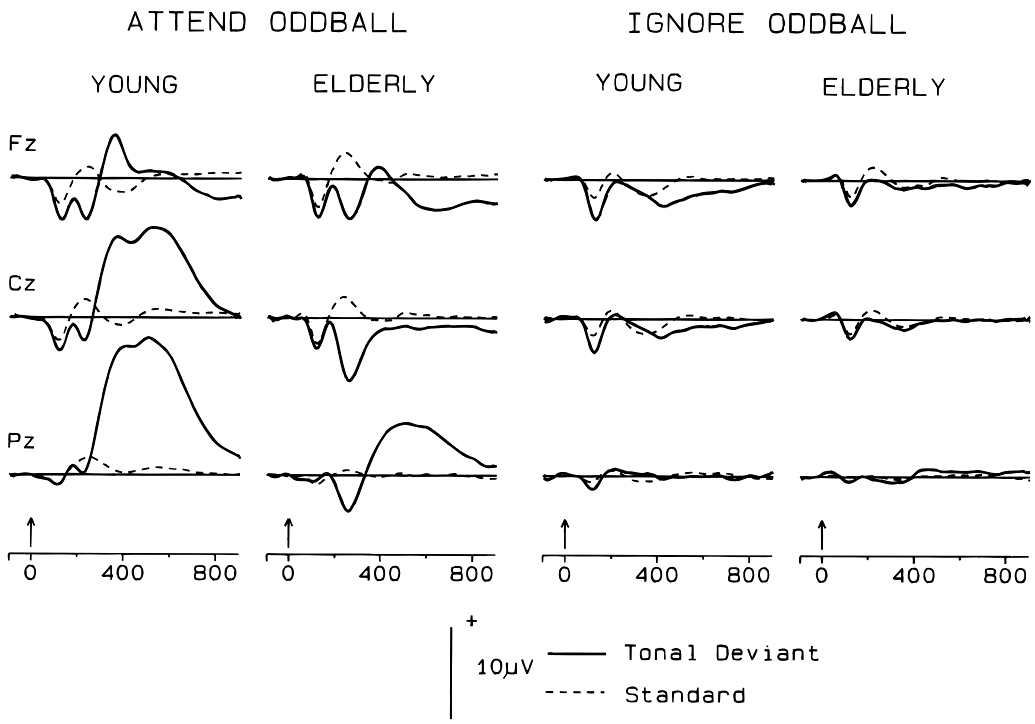

Figure 4. Grand mean event-related potential (ERP) waveforms elicited by the rare oddball tones and standards during novelty oddball blocks for each age group and oddball series (attend and ignore) at the Fz and Pz scalp locations. Arrows mark stimulus onset with time lines every 200 ms.

ated. This exaggeration could have been due to the fact that novel stimuli that repeated did so two blocks after their first presentation. Hence, a comparison of ERP amplitudes elicited by novels in Blocks 3 and 4 with those in Blocks 1 and 2 would include contrasts of novels that repeated and novels that did not. Therefore, two effects, one of which was repetition, and the other recurrence of novelty (both of which induce reductions in novelty P3 amplitude—Courchesne, 1978; Friedman & Simpson, 1994; Knight, 1984) could have contributed jointly to the reduction in novelty P3 amplitude observed here. To determine whether this was the case, the novelty P3s elicited by new items were compared to those that repeated within the *same* block of trials. If the effects of repetition and recurrence are additive, then one would expect to see a difference in the block number analysis between new and repeated

Table 3. *Results of the Attention (Attend/Ignore) × Block Number (Five Levels) × Hemisphere × Caudality (Five Levels) ANOVAs**

	Young					Elderly				
Effect	*F*	*df*	*p*	ε	*f***	*F*	*df*	*p*	ε	*f***
Block (B)	7.14	4,116	**.0001**	0.89	0.25	0.04	4,112	.99	0.85	
Linear (L)	17.99	1,29	**.0002**		0.62	0.08	1,28	.77		
Quadratic (Q)	7.66	1,29	**.009**		0.26	0.01	1,28	.92		
Attention (A)	8.65	1,29	**.006**		0.30	0.55	1,28	.46		
Hemisphere (H)	1.47	1,29	0.23			11.07	1,28	**.002**		0.40
Caudality (CA)	29.25	4,116	**.00001**	0.53	1.00	3.65	4,112	**.03**	0.47	0.13
L × A	3.35	1,29	**.07**		0.11	2.17	1,28	.15		
L × CA	6.60	4,116	**.006**	0.38	0.23	3.98	4,112	**.02**	0.55	0.14
Q × CA	0.87	4,116	.40	0.39		3.23	4,112	**.04**	0.52	0.11
C × CA	3.89	4,116	**.04**	0.40	0.13	1.65	4,112	.19	0.61	
Q × CA × A	2.87	4,116	**.07**	0.39	0.10	0.46	4,112	.64	0.52	
CA × A	5.70	4,116	**.005**	0.53	0.20	2.01	4,112	.14	0.47	
B × CA	3.42	16,464	**.006**	0.30	0.12	2.34	16,448	**.03**	0.38	0.08
H × CA	6.24	4,116	**.001**	0.68	0.21	2.77	4,112	**.06**	0.53	0.10

Note: *Only effects that reached the $p < .10$ level of significance are tabled. **Effect size [computed according to Cohen (1988) and Rosenthal (1991)]; small effect size = 0.10, medium = 0.25, large = 0.40 (Cohen, 1988).

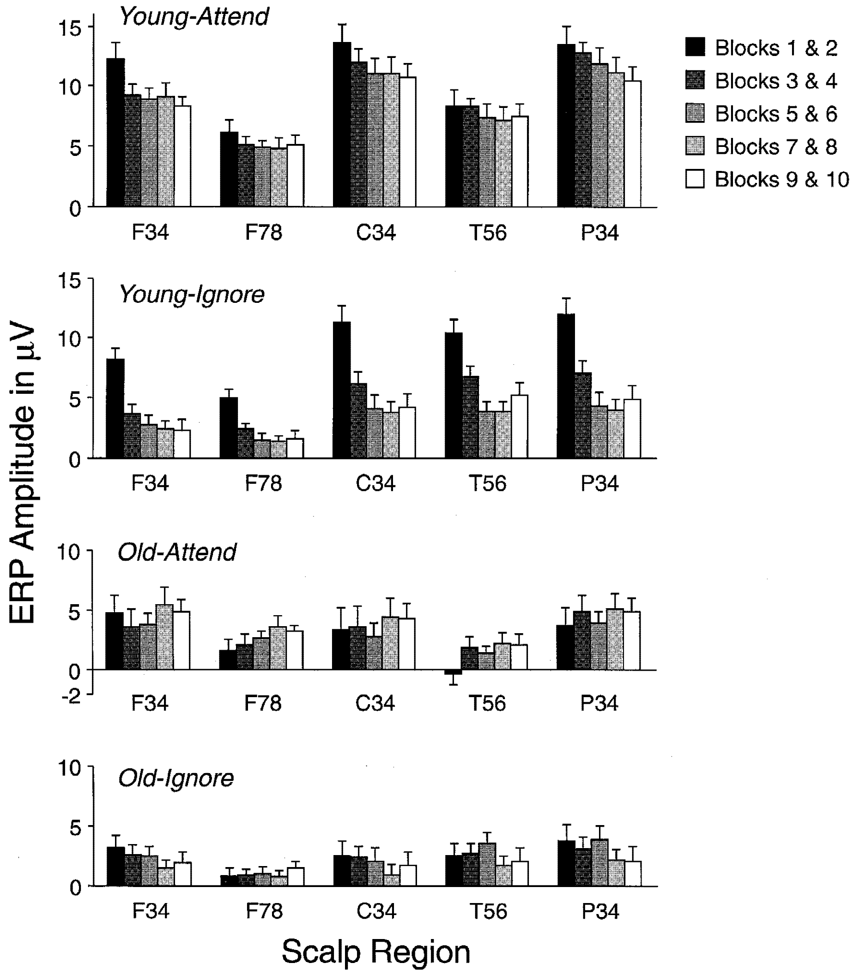

Figure 5. Grand mean averaged voltage indices depicted as a function of block number for both attend and ignore oddball conditions and for both young and elderly age groups at the five anterior–posterior scalp regions. Error bars represent the standard error of the mean.

novels. Due to the way in which the sequences were constructed (see Table 2), this comparison was available only in Blocks 3–8 (there were four new and four repeated items during each of these six blocks). To increase the signal to noise ratios, new and repeated items were averaged separately across two successive blocks of trials (i.e., Blocks 3 and 4, Blocks 5 and 6, Blocks 7 and 8), resulting in six averages per subject (three comprised of repeated novels and three of new novels). This analysis was based on small numbers of trials (maximum of eight per average). Hence, the analysis requires replication with a design that allows for a greater number of trials. The novelty P3 averaged voltages were subjected to an ANOVA, separately for each age group, with one between-subjects factor, Attention (attend/ignore) and three within-subjects factors, Novel Type (new/repeated), Block (3&4/5&6/7&8), and Electrode Location (Fz/Cz/Pz), with tests for trend. For the young, the linear trend was marginally significant, $F(1,29) = 3.47$, $p < .07$, indicating that amplitude decreased monotonically across the three sets of blocks. Importantly, neither the main effect of novel type nor any of the interactions with this main effect or the linear trend were reliable, indicating that the amplitude decrements to new (recurrence) and old (repetition) novel events appeared to be similar. For the elderly, in highly similar fashion to the main analyses detailed earlier, the linear trend was not significant ($F < 1$). As for the young, neither the main effect of novel type nor any of the interactions with this main effect or the linear trend were reliable.[6]

Analysis of Scalp Topography

To determine if there were changes in scalp distribution between the attend and ignore conditions and/or between Blocks 1 and 2 and Blocks 9 and 10 (the beginning and endpoint of the block number function), the data were normalized using the root mean square procedure described by McCarthy and Wood (1985). This analysis was performed separately for each age group. The Block 1 and 2 averaged voltage data in the attend series served as

[6]An additional analysis was also performed to assess these effects. Novelty P3 amplitudes elicited by unique items in Blocks 1 and 2 were compared with P3 amplitudes to new items in Blocks 3 and 4 (recurrence); novelty P3 amplitudes to new items in Blocks 1 and 2 were compared with their repeated counterparts in Blocks 3 and 4 (repetition). Due to loss of trials, this analysis was performed with *n*s of 15 young and 14 old for each of the attend and ignore conditions. In this analysis, the presence of a significant Block (1&2 vs. 3&4) × Type (recurrence vs. repetition) interaction indicates a difference in the amplitude decrement as a function of block. However, this interaction was not significant for either the young, $F(1,28) = 1.82$, $p > .10$, or the elderly, $F < 1$.

the scalar, with the Block 9 and 10 (attend), Block 1 and 2 (ignore) and Block 9 and 10 (ignore) data normalized with respect to this scalar. The normalized voltages were then subjected to an ANOVA with one between-subjects factor, Attention (attend/ignore), and three within-subjects factors, Block Number (1&2/9&10), Hemisphere (left/right), and Caudality (five scalp regions).

Young. The effect of caudality was highly significant, $F(4,116) = 19.06$, $p < .00001$, $\epsilon = .24$, reflecting the overall centro-posterior scalp maximum. However, this main effect was modified by the Attention × Caudality interaction, $F(4,116) = 4.21$, $p < .01$, $\epsilon = .50$, indicating that the scalp distribution of the novelty P3 differed during the attend and ignore oddball series. Post hoc tests indicated that the relative amplitude reduction in the ignore condition at F34 and enhancement at T56 compared with the attend condition were reliable ($p < .05$), as can be seen in Figure 6 (second panel). The Block Number × Caudality interaction approached significance, $F(4,116) = 2.68$, $p < .09$, $\epsilon = .40$, suggesting that the scalp distribution of the novelty P3 may have changed from Blocks 1 and 2 through Blocks 9 and 10. Post hoc testing indicated that the relative reduction for Blocks 9 and 10 at F34 and enhancement at T56 compared with Blocks 1 and 2 were marginally significant. The three-way interaction was not reliable ($F < 1$).

Elderly. For the elderly, the caudality main effect was significant, $F(4,112) = 4.30$, $p <.01$, $\epsilon = .51$, but was not modified by the interaction of Attention and Caudality, $F(4,112) = 1.90$, $p > .10$, $\epsilon = .51$, indicating that, unlike the young adult data, the scalp distributions in the attend and ignore oddball series did not differ reliably. The Block Number × Caudality interaction was, however, significant, $F(12,336) = 3.08$, $p <.02$, $\epsilon = .57$, suggesting that, as for the young, the scalp distribution of the novelty P3 changed from Blocks 1 and 2 through Blocks 9 and 10 (Figure 6, third panel). Post hoc testing revealed that, unlike the young, there was no reliable decrement at F34 from Blocks 1 and 2 through Blocks 9 and 10, but there was a significant *increase* at F78 ($p < .05$). The relative increase in amplitude at temporal sites (T56) was significant ($p < .05$). The three-way interaction was not significant ($F < 1$).

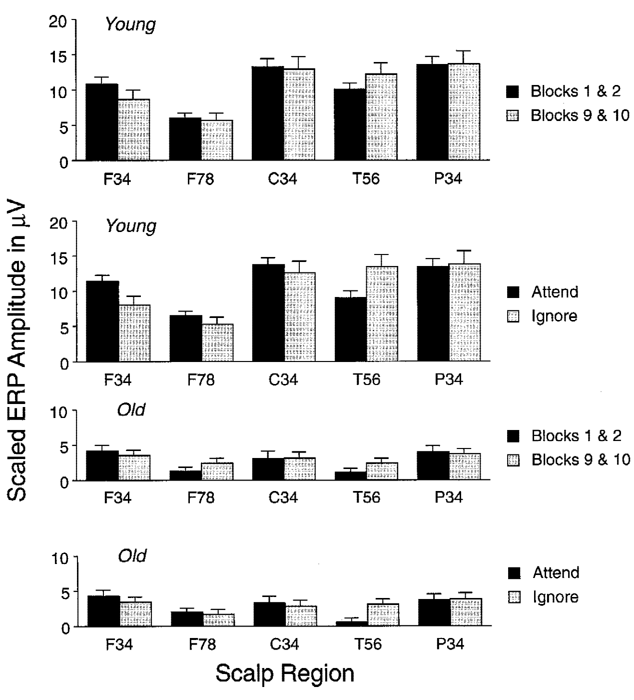

Figure 6. Normalized averaged voltage indices averaged across subjects within each age group. The figure depicts the effect of block number and attention (attend/ignore) on the scalp distribution of the novelty P3. Error bars represent the standard error of the mean.

Summary of ERP Findings

For the young, the novelty P3 in both attend and ignore conditions decreased in amplitude as a function of block number. However, this effect was more prominent at frontal than posterior sites during the attend oddball, whereas it occurred at both frontal and posterior locations during the ignore series. In addition, for the young, the scalp distribution of the novelty P3 was different for the two conditions. Compared with the attend condition, the novelty P3 during the ignore condition was characterized by relatively smaller amplitude frontally, but by relatively greater amplitude at left and right temporal leads. For the elderly, by contrast, there was no systematic decrement in novelty P3 amplitude in either the ignore or attend conditions. Moreover, they did not show a frontal topographic change in the ignore compared to the attend condition, although their novelty P3 in the ignore series was characterized by relative enhancement at the temporal scalp sites (Figure 6).

Discussion

Summary of Findings

In many respects, the current data recorded during the attend oddball task (using independent samples of young and elderly participants) are consistent with the results from previous studies in this series (e.g., Friedman & Simpson, 1994; Cycowicz & Friedman, 1997). The block number functions were highly similar to those obtained in these previous investigations, including the failure of the elderly to show a systematic decrease in novelty P3 amplitude during the attend task. Three new findings have been uncovered in this investigation: (a) the difference, for the young, between the attend and ignore oddball conditions at frontal scalp sites where the novelty P3 showed the greatest "habituation;" (b) age-related differences in the block number function during the ignore series; and (c) topographic differences between the novelty P3 during attend and ignore tasks.

Anterior versus Posterior Aspects of the Novelty P3

As in previous investigations with the novelty oddball (e.g., Friedman & Simpson, 1994), for the young adults the greatest reduction in novelty P3 amplitude during the attend task occurred at frontal scalp sites. By contrast, during the ignore condition both anterior and posterior scalp sites showed marked reductions in amplitude as a function of block number. This difference based on the raw amplitude measures was manifested topographically by a relative reduction (from attend to ignore) in the frontal aspect of the novelty P3. These data add to the evidence that the anterior and posterior aspects of the novelty P3 are most likely subserved by unique neuronal generators, are differentially activated depending on task and stimulus conditions, and reflect unique cognitive functions. In further support of this latter notion, Cycowicz and Friedman (1998) found that the degree of familiarity of environmental sounds modulated differentially the anterior and posterior aspects of the novelty P3. Thus, although the anterior and posterior generators that give rise to the novelty P3 undoubtedly have reciprocal connections, they most likely index separable aspects of information processing.

Functional Significance of Anterior and Posterior Aspects of the Novelty P3

It has been argued previously (e.g., Cycowicz & Friedman, 1997; Friedman & Simpson, 1994) that the frontal aspect of the novelty P3 reflects processes related to orienting. The reduction of the frontal portion of the novelty P3 with experience (i.e., as more novels are presented) is consistent with this hypothesis, as those processes should no longer be necessary once the novel events have been categorized as infrequent nontarget events. However, even when participants did not attend to the stimuli, as in the ignore condition in the present study, the amplitude of the novelty P3 decreased as a function of block number (this reduction was significant only in the data of the young). This finding suggests that the amplitude diminution reflects a change in an *automatic biological* response (i.e., orienting) that captures attention. From a biological point of view such a system would be important because, as more novels occurred and no special action was necessary, there would be no need for the organism to pay attention to stimuli that were not, in some fashion, meaningful.

Based on the findings that (a) the posterior portion of the novelty P3 did not change as markedly as the frontal portion as more novel events were experienced (Cycowicz & Friedman, 1997; Friedman & Simpson, 1994), and (b) that there was a change from a frontally oriented to a more posterior scalp distribution with novel event recurrence, it was suggested that the posterior aspect of the novelty P3 reflects a categorization process. Courchesne (1978) originally suggested that stimuli for which no stored template or representation exists initially elicit a P3 scalp distribution with a frontal orientation. However, stimuli that are easily categorizable or precategorized (i.e., that *do* activate a stored representation) elicit a more parietally oriented distribution. On this view, the current data suggest that, for the young adult participants, as more novel events were delivered they induced the formation of a representation in which their characteristics were stored (consistent with a working memory template; cf., Fabiani & Friedman, 1995). This template enabled these initially uncategorized events to be classified into a discrete group of items (e.g., "novel sounds"), thus accounting for the lack of a significant block number trend at the posterior electrode sites. That is, on the assumption that the posterior aspect of the novelty P3 reflects this classification process (Cycowicz & Friedman, 1997), it would be activated throughout the attend oddball series. However, when participants ignored the incoming stimuli, the sounds were not actively processed aside from the initial "automatic" orienting (reflected by the frontal portion of the novelty P3). In other words, a classification of the sound would not have been as cogent, as no overt discrimination between "target" and "novel" deviants was necessary. This theory would account for the fact that the posterior aspect of the novelty P3 followed the pattern of habituation seen at the anterior sites, even though attention was "captured" by the deviant novel sounds (as reflected by robust N2bs and novelty P3s; cf., Näätänen, 1990; 1992).

The P3b elicited by deviant target tones in an attend oddball task has also been shown to "habituate" (e.g., Polich, 1989; Romero & Polich, 1996), but these effects occur only after several trial blocks have been presented (e.g., Lammers & Badia, 1989; Polich, 1989). No change in P3b amplitude has been observed for single trials from a typical oddball paradigm in the first trial block, although P3b amplitude has been shown to decrement after 5–10 trial blocks, especially at central and parietal scalp sites (Polich, 1989; Romero & Polich, 1996; Wesensten & Badia, 1992). Moreover, the degree of habituation did not appear to vary across the midline electrode sites used in Polich's (1989) or in Romero and Polich's (1996) investigations. Further, P3b amplitude did not change over initial trials when passive and active oddball paradigms were compared (Polich & McIsaac, 1994). In the current study, the P3b elicited by target tones during the attend oddball series did not demonstrate significant habituation across blocks (see footnote 4). Thus, it appears unlikely that the reduction in amplitude of the frontal aspect of the novelty P3 with time on task observed here reflects a similar phenomenon as that shown by P3b "habituation" during oddball tasks.

For the young, and to some extent, for the elderly, the scalp distribution of the novelty P3 differed during attend and ignore conditions, suggesting either that different brain regions are recruited, or that there is an amplitude change in a subset of those generators in the two task conditions (see Johnson, 1993, for a review of scalp distribution issues and caveats). For the young, the novelty P3 during the attend task showed a greater frontal orientation relative to the ignore series (which did not occur for the elderly), but elicited relatively less bilateral temporal scalp activity compared with the ignore series.

The current data add to the evidence from this (e.g., Cycowicz et al., 1996; Friedman, Simpson, & Hamberger, 1993) and other (e.g., Courchesne, 1978; Holdstock & Rugg, 1995; Knight, Scabini, Woods, & Clayworth, 1989) laboratories that the novelty P3 receives contributions from both frontal and posterior generators (see Knight, 1996, for evidence of a hippocampal contribution). It appears that during the ignore condition both anterior and posterior elements are present but, by contrast with the attend task, both show marked "habituation," whereas in the attend task only the frontal aspect shows a significant amplitude decrement with block number. After normalization (for the young), no differences were observed at posterior scalp sites between the attend and ignore novelty P3, whereas the frontal aspect was "reduced" in the ignore relative to the attend condition.

Effects of Aging

Amplitude and topography. During attend novelty oddball tasks, in the elderly, a lack of amplitude decrement of this activity due to repetition has been observed previously (e.g., Kazmerski & Friedman, 1995). These data extend previous age-related findings from an attend oddball task to an identically constructed ignore oddball condition. In addition, they suggest similar mechanisms for the age-related differences obtained in the current ignore condition to those formerly proposed to account for this pattern of results under attend conditions (e.g., Fabiani & Friedman, 1995; see below). In the analysis of scalp topography, the older participants did not show a difference between attend and ignore conditions at the midline frontal scalp site as did the young (i.e., a relative reduction for the ignore novelty P3 compared with the attend condition). This difference suggests that, for the elderly, the frontal generator(s) are as selectively engaged in the ignore as they are in the attend condition, again suggesting an age-related difference in frontal lobe function (cf., Friedman & Fabiani, 1995; see below). On the other hand, in showing a relative enhancement at T5 and T6 to the ignored novels in similar fashion to the young (although the enhancement was not significant; Figure 6), the data suggest that young and old share some aspects of the generator configuration engendered by novel stimuli when those stimuli are ignored. Perhaps, due to presumed reduced brain activity under ignore conditions as a result of fewer activated brain areas than under the attend condition (and, hence a concomitant reduction in the amount of overlap at the scalp), the activity of other generators can be observed at the scalp.

One account of these findings would be that the elderly are just not as responsive as their young adult counterparts, and their lack of novelty P3 habituation is simply due to a "floor effect." In fact, other investigators have found the elderly to be less responsive (in terms of P3 amplitude and eyeblink responses) to startling stimuli (e.g., Ford, Roth, Isaacks, White, Hood, & Pfefferbaum, 1995; see also Kok & Zeef, 1991). However, the stimuli used by Ford et al. (1995) were extremely different than those used here. Moreover, as can be observed in Figures 1–3 of the current report, the older participants produced N2b amplitudes larger than those of the younger adults, suggesting that a generalized reduction in activation or arousal does not characterize the ERP responses of the older participants in the present investigation. Thus, it seems unlikely that reduced responsiveness can account completely for this pattern of results.

Relationship to frontal lobe functioning. A major neuropsychological hypothesis that has been used to account for cognitive aging phenomena is that, with increasing age, there is a change in frontal lobe function (e.g., Albert & Kaplan, 1980; Moscovitch & Winocur, 1992). Recent neuropsychological evidence consistent with this hypothesis suggests that on tests of frontal lobe function, such as the Wisconsin Card Sorting Test (WCST), the elderly make more errors than younger adult controls. The majority of age-related errors typically entail the subject's failure to maintain set (e.g., Haaland, Vranes, Goodwin, & Garry, 1987), with poor scores on this scale of the WCST presumably indicating impairments in the subject's ability to maintain or retrieve procedural rules that have already been learned. In addition, for other cognitive abilities that depend on the frontal lobes, such as abstraction (e.g., Albert, Wolfe, & Lafleche, 1990) and memory for source, that is, retrieval of the initial learning context (e.g., Fabiani & Friedman, 1997; Senkfor & Van Petten, 1996; Trott, Friedman, Ritter, & Fabiani, 1997), the elderly do not do as well as their young adult counterparts. In addition, older adults exhibit difficulty in inhibiting responses to task-irrelevant events (e.g., Hartmann & Hasher, 1991; Rabbit, 1965; Tipper, 1991), a function that depends on intact frontal lobe functioning (e.g., Luria, 1973).

Consistent with difficulty in inhibiting responses to task-irrelevant stimuli, during attend novelty oddball conditions, Friedman et al. (1993), Fabiani and Friedman (1995), and Kazmerski and Friedman (1995) all observed increased false alarm rates to the task irrelevant novel sounds in the elderly relative to the young. Friedman and Simpson (1994) reported that neither frontal nor posterior aspects of the novelty P3 scalp distribution changed for the elderly with time on task as it did for the young (the frontal aspect diminished over time, but the parietal aspect did not change). Fabiani and Friedman (1995), for target stimuli, also showed a highly similar age-related phenomenon.

The conjunction of neuropsychological data reviewed above, brain lesion data implicating dorsolateral prefrontal cortex in the generation of the novelty P3 (e.g., Knight, 1984) and the response to novelty (Woods & Knight, 1986), animal research on working memory (e.g., Goldman-Rakic, 1992), and age-related findings in the novelty oddball paradigm (e.g., Fabiani & Friedman, 1995; Yamaguchi & Knight, 1991) led Fabiani and Friedman (1995) to postulate that the processing of environmental sounds ". . . involves an organized set of processes, whose pivotal aspect may be the formation of working memory templates for target and novel stimuli" (p. 592). This process took time to develop, but was complete in young participants with small amounts of event recurrence. Fabiani and Friedman (1995) suggested that the frontal lobes may be involved in this process. In older people, however, the formation or maintenance of these working memory templates may be disrupted, and the process continues for a much longer time. As the novel events during the ignore series are truly task-irrelevant events, a similar argument appears to be viable here.

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(Received April 25, 1997; Accepted December 11, 1997)