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Age-related effects of different types of noise and stimulus quality: An event-related potential (ERP) study

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Abstract Young and elderly adults were exposed to meaningful conglomerate noise (c-noise) and white noise (w-noise) while they responded to intact and degraded visual stimuli. Complementary to performance measures P3 and the Slow Wave component of the event-related potential were recorded to the visual stimuli. The neural noise hypothesis served as a theoretical framework for the present study. According to this hypothesis older subjects should be affected more strongly by external conditions that increase the level of neural noise than younger subjects.

C-noise and w-noise had contrasting effects on the speed of responding: under c-noise subjects reacted slower, and under w-noise subjects reacted faster than in the quiet condition. The absence of any effect of the two types of noise on the latency of P3 further suggested that the loci of the effect of noise on response speed are response-related processes rather than stimulus-related processes.

At the performance level no evidence was found that elderly subjects were affected more strongly by auditory noise or degradation of stimuli than younger subjects. However, the presentation of c-noise caused a relatively large increase in slow wave negativity in old subjects, relative to the quiet and w-noise conditions. This could indicate that older subjects invested more effort in the task to maintain normal performance levels.

Introduction

Studies on the effects of environmental noise on human performance have not produced very consistent results (Hockey, 1970; Koelega & Brinkman, 1986; Smith, 1989). One reason for this inconsistency could be that effects of noise on cognitive functioning are more specific than originally believed. For instance, different processes such as arousal and distraction may be responsible for the effects of noise on human performance (Broadbent, 1963, 1979; Loeb, 1986). These processes may also depend on the type of noise that is used. For instance, it has been suggested that intermittent noise composed of unexpected, meaningful and novel sounds is more distracting than monotonous noise (Broadbent, 1979). This type of noise has also been referred to as meaningful noise or "conglomerate noise" (c-noise). Alternatively, the interfering effect of monotonous noise on performance has usually been ascribed to its arousing properties. The latter assumption receives support from studies showing that white noise (w-noise) increases speed of responding at the cost of accuracy (Hockey, 1970; Hockey & Hamilton, 1983; Kahneman, 1973).

Although many studies have examined the effects of noise on performance in young subjects, research with elderly persons is rare. The present experiment is inspired by the hypothesis that age-related changes in performance can be attributed, at least in part, to an increase in neural noise in elderly subjects. The neural noise hypothesis holds that various age-related neurobiological changes result in a decreased signal-to-noise ratio throughout the central nervous system (Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Welford, 1984). As a consequence, responses become slower while more signals are missed and false alarms are given. The latter hypothesis receives support from the finding that adult aging is accompanied by elementary neuro-anatomical and neurophysiological changes in the central nervous system. First, the strength of incoming signals may become weaker in old subjects, due to impairment of the perceptual system (Fozard, 1990; Welford, 1984). Second, with a declining number of neurons and loss of neuro-transmitters over the life span (see also Scheibel & Scheibel, 1975; Selkoe, 1992), the transmission rate of signals is expected to weaken, which in turn may increase the level of noise in neural systems. An additional assumption of the neural noise hypothesis is that the level of neural noise depends not only on biological conditions within the central nervous system, but also on the quality of stimuli in information processing tasks. For instance, in a choice reaction task the strength, or neural representation, of the signal can be weakened by adding random background noise to the stimulus patterns in the display (Cremer & Zeef, 1987). Other factors that may increase the level of neural noise are environmental conditions such as distractive sounds or auditory noise (Welford, 1981, 1984).

It should be noted that to date the neural noise hypothesis has not received strong empirical support (see also Salthouse, 1985; Salthouse & Lichty, 1985). This could be due to the fact that in previous studies the conditions that were used to manipulate the level of neural noise were not effective enough. Another factor could be that these studies relied entirely on performance measures, while electrocortical measures may be more suitable since they are more directly related to the activity of the central nervous system.

In the present study, the assumptions underlying the neural noise hypothesis of aging will be tested by exposing old and young subjects to two types of noise, c-noise and w-noise, while reacting to intact and degraded visual stimuli. The reason for selecting c-noise is that we expected that this type of noise would be more effective in inducing age-related decrements in performance than an artificial stressor like w-noise that has been investigated in previous studies. It is hypothesized that a higher level of internal noise in older subjects makes them more vulnerable to external (auditory and visual) noise than young subjects. To be more specific, it is anticipated that the detrimental effects of auditory noise, in particular c-noise, and the effects of stimulus degradation on performance will be larger in old than in young subjects. These hypotheses will be tested by using both performance measures and components of the event-related potential (ERP) as convergent measures of the effect of noise on information processing.

The P3 and Slow Wave (SW) components of the ERP are particularly relevant for testing the assumptions of the present study. There is considerable evidence that the amplitude of the P3 component of the ERP is proportional to the amount of information that is delivered by the stimulus (Donchin & Coles, 1988; Duncan-Johnson, & Donchin, 1977; Gratton, Bosco, Kramer, Coles, Wickens, & Donchin, 1990; Johnson, 1988; Kok, 1990; Ruchkin & Sutton, 1978). This view also receives support from studies showing that perceptual degradation of visual stimuli decreases the amplitude of P3 (Kok, 1986; Kok, van de Vijver, & Rooyakkers, 1985; Ruchkin, Sutton, Kietzman, & Silver 1980). The second ERP component that is relevant for the present study is the SW. This ERP component has a positive polarity at posterior scalp sites, and a negative polarity at the more frontal electrode sites. There is also evidence that positive and negative SW components are functionally different. Positive SW usually shows an increase in amplitude in combination with a smaller P3, with greater perceptual demands of the task (Kok & Looren de Jong, 1980; Ruchkin et al., 1980). In addition, negative slow waves with a frontal-central distribution appear to reflect primarily central processing demands in complex cognitive tasks requiring transformation in working memory (Kok, 1990; Rösler, Heil, & Glowalla, 1993; Ruchkin, Johnson, Mahaffey, & Sutton, 1988). Thus, in addition to P3, positive and negative SW components may provide useful additional information concerning the effect of noise on covert information processing activities in the brain.

P3 and SW components may also shed light on the different ways these processes could be affected by noise in old and young subjects. Previous aging studies have demonstrated consistent age-related changes in P3 latency and in the scalp topography of P3 and SW components (see Bashore, 1990; Kok & Zeef, 1991, for extensive reviews). P3 latency is shown to increase systematically with age. In addition, studies have reported smaller task effects on P3 amplitude with advancing age. For instance, in the classical oddball task, the amplitude enhancement of P3 to infrequent visual stimuli relative to frequent stimuli is less pronounced in old than in young subjects (Czigler, Csibra & Ambro, 1996; Looren de Jong, Kok, & van Rooy, 1989). This finding may be taken as a manifestation that old subjects are less reactive to the information quality of task relevant stimuli than young subjects. Old subjects also show a greater diffuseness of the midline scalp topography of P3. An implication of this topographical difference is that old subjects have slightly smaller P3s at posterior sites, but larger P3s at frontal electrodes than young subjects.

A drastic reduction of the negative slow waves has been reported for old subjects, which is most prominent at the frontal scalp sites. It has further been suggested that the reduction of the frontal slow wave in the elderly could reflect an age-related change in inhibitory functions of the frontal lobe. The inhibition hypothesis has been substantiated by behavioral studies showing that old subjects are less able than young subjects to inhibit the processing of distracting or task-irrelevant stimuli (see Friedman & Simpson, 1994; Kok & Zeef, 1991; Kok, Zeef, Kenemans, & Sonke, 1995, for a further elaboration of this hypothesis).

With respect to P3 and SW amplitude the following specific predictions are made: (a) Both degradation of stimuli and external noise will reduce the amount of effective stimulus-related information that is transmitted, and will therefore increase the level of neural noise in subjects. (b) These effects will become manifest in a more drastic reduction of P3 amplitude and a concomitant increase in the amplitudes of positive and negative SW in old than young subjects. It is further anticipated that these ERP effects will be more pronounced for c-noise than for w-noise.

Method

Subjects

Two age groups that each consisted of 12 right-handed subjects, a young group of students (20–30 years, mean = 22.5, sd = 2.5) and a group of older adults (65–75 years, mean = 68.8, sd = 2.2) were selected. In each group the number of males and females was equal. The students participated in this experiment as part of their study commitment and were not paid. The older adults were drawn from a larger subject pool (recruited in an earlier phase by advertising) and paid for participation. All subjects had at least a high school education and none of them reported a history of neurological disorders or any current use of medication. All subjects were free from physical complaints and mentally in a good condition. A common Dutch intelligence test (GIT) and the digit symbol test (DS) of the WAIS were also administered. Mean scores were: young subjects IQ = 122, DS = 65 and old subjects IQ = 124, DS = 49. The lower DS score in elderly subjects confirms the findings from other studies that elderly subjects have lower scores on tests of fluid intelligence than young subjects (Rabbit 1992; Salthouse, 1985). However, since elderly and young subjects did not differ significantly in their IQ scores it may be assumed that the two age groups did not differ in general intellectual ability.

Subjects were also tested for normal or corrected-to-normal vision (minimal .5 as established by a Landolt chart). A hearing test was administered for each participant. None of the subjects showed considerable hearing loss, a maximum criterion for hearing losses in the lower frequency range (250, 500, 1000 Hz) was set to 20 dB(A) and for the higher frequency range (2000, 4000, 8000 Hz) to 35 dB(A). As the normal aging process causes hearing in high frequencies to become less sensitive, a higher threshold in this range was chosen for the old subjects.

Apparatus

The experimental configuration that was used for stimulus presentation and data-acquisition consisted of an Apple Macintosh and an IBM PC-AT computer (see Cremer, van der Schaaf, & Verheyden, 1991). Subjects sat in a dimly lit, sound attenuated room facing the microcomputer (screen diagonal 22 cm or 17.5 degrees of arc) at a distance of 70 cm in front of the subjects head. The average luminance of the CRT-display was 0.08 cd/m^2. Stimuli were black and appeared on a white background. Each block of trials was preceded by two instruction frames each lasting for 10 seconds. The first frame instructed the subject to sit at ease and to be attentive. The second frame contained specific information about the relation between stimulus and response. A fixation mark was always on the screen when no stimulus was presented.

Noise

C-noise was played back by a Tascam-32 tape recorder and w-noise was produced by a Hewlett Packard noise generator (H01–3722A). Noise was presented to the subject over a Sennheiser headphone (HD414 SL) binaurally in mono by a padded headphone. Sound intensities were calibrated using a Bruel & Kjaer sound level meter. C-noise consisted of a mixture of realistic sounds from an airport terminal, a metal factory, road traffic, and sounds from a swimming pool. The tape recording of C-noise lasted 5 min and was composed of a repetition of fragments that each lasted for 20 s. The 20-s fragment consisted of a continuous presentation of the mixture of varying sound items mentioned above. These sounds ranged from 31 Hz to 3100 Hz, and from 40 to 80 dB(A). Higher frequency sounds showed higher intensities (e.g., 2000 Hz sounds had an intensity of 80 dB(A)). White noise consisted of a 5 Hz cycle with an intensity of 85 dB(A).

Stimuli

Intact stimuli were digits (2, 3, 4 and 5) that were composed of dots in a 5 × 7 matrix (19 × 14 mm or 1.55 deg × 1.15 deg) and surrounded by a rectangular frame of 9 × 11 dots (25 × 30 mm or 2.05 deg × 2.45 deg). Degradation was achieved by randomly distributing 12 dots from the surrounding frame near the digit, leaving the stimulus intensity unchanged.

Procedure

A stimulus block contained 128 stimuli, consisting of an equal number of randomly presented intact and degraded digits. One block lasted about 5 minutes. The inter-stimulus interval ranged randomly between 3660 ms to 3910 ms. The visual stimulus was presented for 200 ms. A fixation mark was always on the screen when no stimulus was presented.

The entire experiment lasted approximately 2.5 hours and began with a brief description of the experiment. The headphone was on the subject's head during all experimental sessions. In the noise conditions the noise was played over the headphone one minute before instruction frames were presented on the screen. Subjects were requested to take a relaxed posture, to minimize head and eye movements and blinks. They were also instructed to restrict body and head movement and to restrict eye movements to a minimum during the experimental sessions.

Subjects were instructed to react quickly but accurately to the digits by pushing one of four buttons (two buttons were placed under the left hand and the other two buttons were placed under the right hand). Digits 2 and 3 corresponded with the middle and index finger of the left hand and digits 4 and 5 corresponded with the index and middle fingers of the right hand, respectively. Two practice sessions of 64 trials each were presented, once under exposure to c-noise and once under w-noise. Practicing continued until all subjects performed below a 20% error limit.

There were three conditions: c-noise, w-noise and quiet, which were presented in a balanced order across subjects. Between each noise condition a break of approximately 15 minutes allowed relaxation.

Electro-cortical measures

Standard tin Electro-cap electrodes were used from monopolar EEG derivations. EEG was recorded according to the international 10–20 system (Jasper, 1958) from Fz, Cz, Pz, and Oz and referred to linked ears (A1 and A2). Electrodes for measurement of the electro-oculogram (EOG) were placed at the outer canthi of each eye (horizontal eye movement detection), infra-orbital and supra-orbital (vertical eye movement detection). A ground electrode was placed at the forehead just above the nose. Signals were recorded on paper and digitized on-line by the A/D system. EEG, EOG and button presses were monitored on-line for artifacts and saturation of the AD converter. The EEG and EOG were pre-amplified and filtered by a Nihon-Kohden nine channel polygraph. A high-frequency cut-off of 35 Hz and a time constant of 5 s was applied for both EEG and EOG. All single-trial data were stored on hard disk for later analyses.

Data reduction and analysis

Performance measures

Extreme slow reaction time (RT > 1500 ms) and extreme fast reaction time (RT < 250 ms) trials were left out of the analyses: the average number of these trials, including omission responses, was < 3%. Statistical tests (repeated measures ANOVAs) were performed for the performance data (RT and accuracy). In these analyses the factors were: NOISE (quiet, w-noise, c-noise), TASK (intact or degraded stimuli) and AGE (young versus old subjects).

ERP analyses

EEG, EOG were digitized at a rate of 100 Hz, starting 200 ms before stimulus onset until 1080 ms after stimulus onset. In order to discard artificial low frequent drift in the EEG, the EEG was aligned to the mean value of an epoch. Only trials associated with correct RTs ranging between 250–1500 ms were included in the ERP analyses. These EEG trials were corrected for horizontal and vertical eye movements and blinks, using the method of regression analyses in the frequency domain as introduced by Woestenburg, Verbaten, and Slangen (1983). The EEG was averaged for the separate conditions, and the mean value of the prestimulus epoch was subtracted from the EEG.

After visual inspection of the averaged ERP waveforms the following epochs were selected for scoring of the amplitudes of ERP components: 460–600 ms for P3 and 620–800 ms for SW. Note that although P3 latency was slightly longer in old than in young subjects these epochs corresponded fairly well with the ERP areas in which these components were maximally active for both young and old subjects (see also Figures 1 and 2). The average values (area measures) in these epochs were submitted as dependent variables to ANOVAs with the factors AGE (young or old subjects), NOISE (quiet, w-noise and c-noise), TASK (intact or degraded stimuli), and ELECTRODES (Fz, Cz, Pz, and Oz). Since repeated-measure designs were used in ANOVAs, the Greenhouse-Geisser (Type I) epsilon error corrections were used to compute the P levels for the tests. P3-latency was measured as the moment of maximal positive deflection at the Pz electrode in the 270–650 ms epoch. This epoch was wide enough to encompass P3s of young and old subjects.

Results

Reaction times and error rates

The means and deviations of RT and error percentages are presented in Table 1. Old adults were generally slower ($F(1,22) = 31.53$, $P < .001$) than young adults. RTs under noise differed significantly from RTs in the quiet condition ($F(2,44) = 18.82$, $P < .001$). Separate ANOVAs verified that subjects reacted faster under w-noise ($F(1,22) = 4.83$, $P = .039$) but slower under c-noise ($F(1,22) = 19.48$, $P < .001$) than in the quiet condition. Reactions to degraded stimuli were slower ($F(1,22) = 26.65$, $P < .001$) and less accurate ($F(1,22) = 27.09$, $P < .001$) than to intact stimuli. These effects appeared to be stronger under noise than in quiet (NOISE by TASK interaction: RT: $F(2,44) = 4.98$, $P = .011$; Errors: $F(2,44) = 3.54$, $P = .038$). No significant interactions between age and task conditions, or between age and noise were found for performance measures.

Table 1 RT and error percentages (sd in parentheses) for old and young subjects, in quiet, c-noise and w-noise. Left: intact condition, right: degraded condition.

Stimuli	Intact RT (sd)	ERROR (sd)	Degraded RT (sd)	ERROR (sd)
Quiet				
young	703 (59)	2.9 (2.5)	714 (66)	3.7 (3.5)
old	796 (62)	3.4 (2.8)	827 (53)	6.1 (2.8)
C-Noise				
young	718 (40)	2.6 (2.9)	766 (74)	6.9 (9.8)
old	806 (29)	3.8 (4.9)	873 (38)	9.2 (5.2)
W-Noise				
young	684 (44)	1.8 (3.0)	732 (54)	6.4 (5.0)
old	773 (51)	2.4 (2.0)	821 (47)	10.4 (4.9)

P3-latency

As expected, old subjects showed longer P3 latencies than young subjects ($F(1,22)$: 28.64, $P <$ .001). No significant effects of NOISE or TASK (degradation) were found on P3 latencies. Also, no significant interactions between AGE with TASK or NOISE were found.

P3 and SW amplitude measures

Figures 1 and 2 illustrate the effects of different conditions (superimposed for intact-degraded stimuli and different noise conditions, respectively) on the grand average ERP waveforms. As can be seen in these figures, the averaged ERPs are characterized by a sequence of components that vary in morphology according to the scalp location. Old subjects show a more diffuse midline scalp distribution than young subjects. The most prominent components are:

- at the anterior recording (Fz): N2 and a negative SW,
- at the parietal recording (Pz): P3 and a positive SW, and
- at the occipital site (Oz): N1.

Statistical analyses will be restricted to P3 and SW.

Figure 3 presents the area measures for P3 and SW for different midline electrodes, age

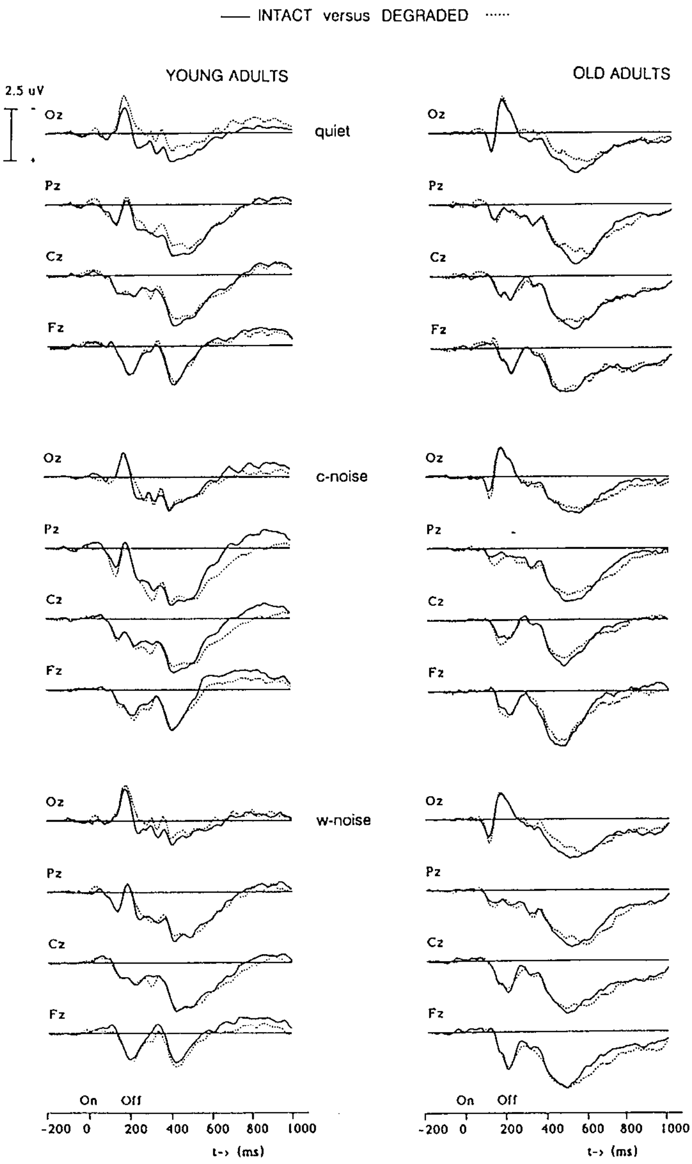

Figure 1 Intact/degraded superpositions of ERPs (midline Oz, Pz, Cz and Fz) for young and old subjects in quiet and two noise conditions.

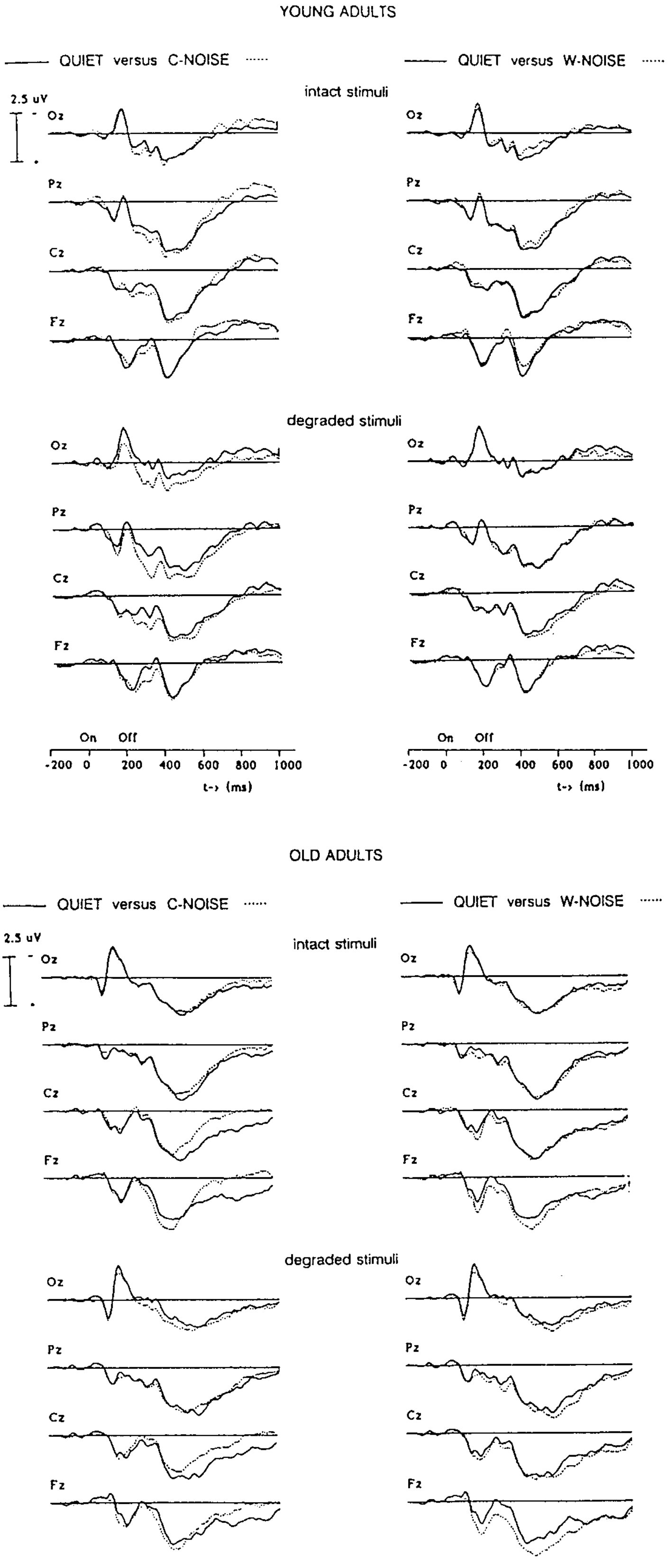

Figure 2 Quiet/noise superpositions of ERPs (midline Oz, Pz, Cz and Fz) for young (upper panel) and old (lower panel) subjects, and intact and degraded conditions.

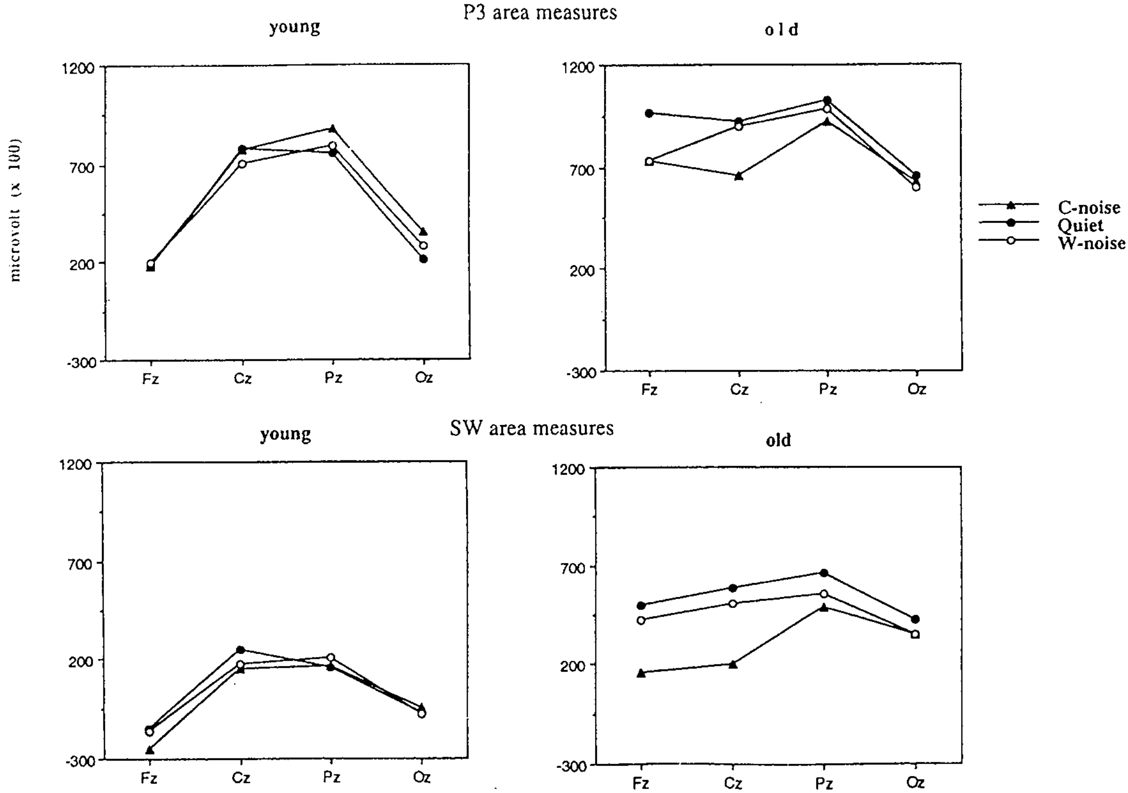

Figure 3 Average area measures (pooled across intact/degraded conditions) for P3 (upper figures) and SW (lower figures), plotted as a function of midline electrodes (Fz, Cz, Pz, Oz), age groups, and noise conditions.

groups, and noise conditions. This figure shows that the topographical distribution of these components across the scalp is more diffuse for old than for young subjects. Furthermore, young subjects display a negative SW at frontal electrode sites, while in old subjects this frontal negativity of SW is lacking, and SW is manifested as a prolonged positivity.

ANOVAs of the area measures showed significant main effects of AGE for P3 ($F(1,22) = 49.8$ $P < .01$), and significant effects of AGE ($F(1,22) = 99.9$ $P < .01$), NOISE ($F(2,44) = 4.3$, $P < .01$) and TASK ($F(1,22) = 4.2$, $P < .05$) for SW. These effects indicate that old subjects showed larger positive P3 and SW components at all electrode sites than young subjects (Figure 3). Also, noise elicited a greater negativity in the SW area than the quiet condition, while degraded stimuli elicited a more positive SW than intact stimuli (Figure 1). P3 also showed a significant interaction between AGE and ELECTRODES ($F(3,66) = 7.8$, $P < .01$) which indicates that old subjects had a more diffuse topographical distribution of P3 over the midline locations than the younger subjects (see Figure 3). Notice also that old subjects had a much more positive P3 at anterior sites than young subjects.

Of particular importance for the hypotheses of the present study are statistical effects that reflect interactions between age and noise, and between age and task. As stated earlier, such interactions would support the hypothesis that old age and external sources of noise (e.g., stimulus degradation, auditory noise) operate through a common neural mechanism. However, no significant interactions were found between age and noise or between age and task, for P3 and SW components, in the overall ANOVA.

Despite the absence of significant overall interaction effects, there were marked age-related differences in the morphology of the ERPs elicited in the two noise conditions. Note that the effect of w-noise, as compared with quiet, does not seem to differ appreciably between age groups. In contrast, c-noise effects on P3 and SW components appear to be larger in old than in young subjects (see Figure 2: left upper and lower panels). These observations were confirmed in two separate ANOVAs that were carried out on quiet versus w-noise and quiet versus c-noise conditions, respectively. The latter analyses permitted a more direct evaluation of the specific type of noise that was used relative to the quiet condition than the overall ANOVA. When quiet was compared with c-noise the following results were obtained: (a) c-noise had a significant effect on SW (increase in negativity: $F\ (1, 22) = 8.4$, $P < .01$) and (b) there were significant AGE × NOISE interactions for both P3 and SW area measures (P3: $F(1,22) = 4.1$, $P < .05$; SW: $F\ (1,22), = 4.2$, $P < .05$). These AGE × NOISE interactions in the separate ANOVAs confirm the visual impression of Figures 2 and 3 that c-noise elicited a negative shift in the ERP waveform which affected both P3 and SW amplitudes, and was more conspicuous in old than in young subjects. However, since the SW in old subjects always keeps a positive polarity, the interaction became manifest as a decrease in amplitude (i. e., smaller positivity) of the SW for these subjects.

Summary

The major results can be summarized as follows:

- C-noise and w-noise had different effects on RT: c-noise induced slower reactions and w-noise induced faster reactions. No significant interactions were found between age and noise, and age and task for performance measures.
- The elderly subjects showed a more diffuse scalp distribution of P3 and SW area measures, and longer P3 latencies than the younger subjects.
- C-noise and w-noise also produced different ERP patterns in old subjects: under c-noise old subjects showed a prolonged negativity in the areas of P3 and SW as compared with the quiet condition, whereas in the young these effects were less conspicuous. Under w-noise these effects did not occur.

Discussion

As expected, degraded stimuli elicited slower and less accurate responses than intact stimuli and old subjects were slower and somewhat less accurate in responding than young subjects. However, the analysis of performance measures failed to confirm the prediction that old subjects would be slower and less accurate under c-noise, especially when perceptual processing demands were high. Thus, on the performance level no support was found for the hypothesis that old subjects are more vulnerable to external conditions that increase the level of neural noise in the central nervous system than young subjects. It should be noted that in the present study old subjects were healthy, highly educated and strongly motivated. This could explain why age-related experimental effects were rather small. In addition, relatively small groups of old and young subjects were used which could have decreased the power of the F tests in the analyses of variance of the performance data. In a study reported elsewhere (Kok, Lorist, Cremer, & Snel, 1994) we used regression analyses ("Birren plots") of reaction times and error percentages in visual RT tasks that were obtained in relatively large groups of old and young subjects. In the latter study it was demonstrated that old subjects were less accurate than young subjects in the more demanding RT tasks when these tasks had to be performed under noise, but not in the quiet condition.

Another speculation why old subjects did not show a larger decrement in performance than young subjects in conditions that were assumed to increase the level of neural noise is that the old subjects were able to compensate for the detrimental effects of noise on performance, by allocating more mental effort. The latter hypothesis, that will be further elaborated below, was based on the observation that old subjects showed larger amplitudes of sustained negative waves in the ERP than young subjects in conditions when meaningful noise (c-noise) was presented.

An interesting finding was that, irrespective of the age of subjects, w-noise and c-noise had contrasting effects of the speed of performance: under c-noise subjects were slower, but under w-noise subjects were faster than in the quiet condition. This result confirms earlier suggestions that c-noise and w-noise elicit different types of processes. The global pattern of performance measures under w-noise (i. e., faster and somewhat less accurate response; see table 1) is reminiscent of earlier results (cf. Broadbent, 1971; Hockey & Hamilton, 1983) showing that white noise causes a shift in the speed-accuracy trade-off (i.e., faster and less accurate reactions). Alternatively, the fact that c-noise was associated with slower reactions as compared with the quiet condition is probably more easy to reconcile with a distraction interpretation of this type of noise.

P3 latency and performance measures

In accordance with earlier findings (see Bashore, 1990; Kok & Zeef, 1991) old subjects showed longer P3 latencies than young subjects. However, the age-related prolongation of P3 was neither affected by noise nor by task demands. There is ample evidence to suggest that P3 latency reflects the time to evaluate the stimulus, and is independent of response-related factors, such as a shift in the response criterion (Donchin & Coles, 1988; Kutas & Donchin, 1980; Magliero, Bashore, Coles, & Donchin, 1984). In the present experiment a dissociation was found between the effects of noise on RT and P3 latency. C-noise and w-noise had contrasting effects on the speed of the responses, but did not affect P3 latency. This finding provides further support for the view expressed above that the loci of interference caused by environmental noise are the response-related processes (e.g., response-selection) and not the perceptual-central processes.

ERP amplitude: P3 and SW

At the frontal and central electrode sites old subjects showed larger P3s than young subjects. Surprisingly, even at the posterior sites P3 amplitudes were slightly larger in old than in young subjects. In accordance with previous findings old subjects showed a more diffuse midline scalp distribution of P3 and SW components, and a lack of fronto-central SW negativity (Figure 3). An age-related decrease in negative slow waves has also been reported in earlier studies, which probably reflects structural changes in cerebral organization with advancing old age (Looren de Jong, Kok, & van Rooy, 1988a; Pfefferbaum, Ford, Wenegrat, Roth, & Kopell, 1984; see also Kok & Zeef, 1991, for a review).

ERP amplitude results did not confirm the prediction of a specific effect of age on P3 and SW amplitudes in the degraded condition. Degraded stimuli elicited a larger positive SW as expected (see Figure 1) but there were no indications that this effect was more pronounced in the elderly subjects. However, in accordance with our predictions, separate ANOVAs verified that noise type affected the amplitude of P3 and the SW: c-noise had a more prominent effect on SW amplitude than w-noise. This became manifest in a sustained increase in negativity (or: decrease in positivity) of the SW. An interesting second finding from the same analyses was that the increase in sustained negativity under c-noise was more prominent in old than in young subjects (see Figures 2 and 3). As noted earlier, old subjects always showed positive SW's at all electrode sites and in all conditions. Therefore, in old subjects the increase in sustained negativity did not become manifest as an absolute increase in cortical negativity, but rather as a decrease in amplitude, or smaller positivity, of the positive SW and P3 under c-noise relative to the quiet condition*.

These results indicate that electrocortical activity in elderly subjects was affected more strongly by meaningful noise than neutral w-noise. The question that can be raised is to what extent the increase in slow negativity that was induced by noise is functionally related to the task-induced negativity that has been reported in prior studies. Several studies with young subjects have shown that slow negative waves in the ERP reflect processing demands in complex visual tasks (Mecklinger, Kramer, & Strayer, 1992; Rösler et al., 1993; Ruchkin et al., 1988; Wijers, Otten, Feenstra, Mulder, & Mulder, 1989). In addition, Looren de Jong, Kok, Woestenburg, Logman, and van Rooy

* It is unlikely that these effects were caused by a greater latency variability (or "jitter") of the ERP components in old subjects, as suggested by one of the reviewers of this paper. First, a greater latency variability should have resulted in smaller amplitude and more diffuse P3/SW waveforms in old subjects. However, in the present study old subjects showed P3s with a larger amplitude than P3s in young subjects. Second, latency jitter is an artifact caused by a greater variability of neural processes underlying ERP waveforms in task conditions that usually also elicit longer and more variable reaction times. It is hard to understand how this could have resulted in a highly specific effect, like the enhancement of slow wave negativity at fronto-central electrode sites in elderly subjects under c-noise.

(1988) reported an increase in sustained negative potentials in elderly subjects in a complex visual search task. Ruchkin et al. (1988) further suggested that slow negative waves reflect activation of working memory in complex and highly demanding cognitive tasks. Although the tasks that were used in the present study were not designed to activate working memory processes, it is possible that the enhanced SW negativity under c-noise relative to the quiet condition reflected an increase of the processing demands of the task. Furthermore, the fact that these effects were larger in old than in young subjects, could mean that processing demands were higher for old than for young subjects.

It also remains to be explained why the significant AGE × NOISE interaction was only found for ERP and not for the behavioral measures. Previous research has demonstrated that environmental stressors often induce "strategy" effects such as adaptation of criteria for decision, task set and allocation of mental effort (Hockey, 1986; Hockey, Coles, & Gaillard, 1986; Hockey & Hamilton, 1983). Since c-noise did not lead to a larger decrement in performance in old than in young subjects, it can be speculated that in old subjects the enhanced slow negativity reflected regulatory and strategy aspects of the control of behavior that served to compensate for the disrupting effects of c-noise. Interestingly, Sommer and Leuthold (1993) recently reported similar covert effects of a stressor on ERP components. These authors found enhancement of a late slow negative wave component under alcohol in a visual discrimination task, in the absence of any effects on behavior. They further suggested that this dissociation of measures could reflect that subjects invested additional processing resources in order to maintain normal performance levels.

In summary, the present results showed that young as well as old subjects reacted slower under c-noise and faster under w-noise, than in the quiet condition. The absence of any effect of noise on the latency of P3 suggests that the locus of the effect of both types of noise on response speed are the response-related processes rather than the stimulus-related processes. In addition, no behavioral and ERP evidence was found that noise specifically interfered with the perceptual demands of the task, or that perceptual-central processes in old subjects were more impaired by noise than in young subjects. Thus, our results did not provide direct support for the hypothesis that old subjects are more vulnerable to external conditions that increase the level of neural noise than young subjects. However, the finding that c-noise affected slow wave negativity but not the performance of old subjects could be an indication that old subjects allocated extra effort to compensate for the disruptive effect of this stressor on performance.

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