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THE EFFECT OF SONAR EXPERIENCE AND AGE ON THE AUDITORY EVENT-RELATED POTENTIAL

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Summary

Problem: Sonar operators listen to and interpret complex auditory signals for thousands of hours over a period of years. They develop an expertise in tone discrimination that could be expected to influence how they process auditorily presented information, which would change their task-related brain electrical activity. The evidence thus far suggests that the brain electrical activity of experts is different from that of novices.

Objective: Experts may be of different ages and several studies have shown that ERPs change with aging. Therefore, the affect of sonar experience and age on auditory event-related potentials (ERPs) was investigated.

Approach: An "oddball" frequency discrimination task of 300 trials was used to elicit ERPs at sites Fz and Pz. A three-group design was used, a young sonar-inexperienced group, a sonar-experienced group, and an age-matched comparison group for the experienced group.

Results: Overall, higher component frontal amplitudes were found for the older groups. The sonar-experienced group displayed higher target mean amplitudes than the age-matched inexperienced group for the N1-P2 complex and the P2 and P3 components.

Conclusions: The results suggest that experience and age has an effect on ERP component amplitude and distribution. The results concerning age and ERPs, support and extend the results of previous studies. The present study used groups of subjects that were that much younger and closer in age than those used in previous studies. We found that age-related ERP differences occur at a much younger age than reported elsewhere. Although attentional and stimulus evaluation processes have been heretofore linked to ERP component parameters, our study found that they may be enhanced with real-world task experience. ERP studies should control for the possible confounds of task experience and age.

Introduction

The primary task of a sonar operator is to detect and identify target stimuli. Targets must be discriminated from frequently occurring nontarget stimuli presented against a constant background noise. This discrimination experience meets the criterion suggested for the development of automatic processing and may result in unique processing strategies as proficiency on tasks that require consistent mapping of target stimuli is obtained (Schneider & Shiffrin, 1977). Kobus, Beeler, and Stashower (1987) and Kobus and Stashower (1988) have suggested that extensive experience gained on such tasks may result in a change in processing strategies that is reflected in the pattern of brain electrical activity across the scalp.

Event-related potential (ERP) studies have shown that automatic processes can be distinguished from controlled processes by analyzing ERP component structure (Hoffman, Simons, & Houck, 1983; Klein, Coles, & Donchin, 1983; Kramer, Schneider, Fisk, & Donchin, 1986; Rosler, 1981). Specific ERP components have been correlated with specific cognitive mechanisms related to task experience and automatic and controlled processes. For example, N100, the N1-P2 complex and the P2 component have been associated with sensory filtering, attention, and stimulus selection (Hillyard & Kutas, 1983; Lindholm & Koriath, 1985; Ritter, Simson, Vaughan, & Macht, 1982). Whereas, the P3 component has been linked to working memory (Klein et al., 1983); the evaluation of task-relevant stimuli (Duncan-Johnson, 1981; Duncan-Johnson & Donchin, 1982; Johnson, 1986); the use of limited resources (Hoffman et al., 1983); and automatic and controlled processes (Kramer et al., 1986).

Kobus et al. (1987, 1988) found that experienced sonar operators, when compared to inexperienced operators, displayed significantly larger N1-P2 complex, P2, and P3 amplitudes at the Fz electrode site. The authors stated that although the site of the recording does not necessarily reflect the origin of the activity, the scalp distribution may be indicative of the differences between automatic and controlled processing. This hypothesis was based on the differences found between the ERP parameters of highly experienced subjects as compared to inexperienced subjects. Experienced subjects displayed larger N1-P2, P2, and P3 amplitude differences between target and nontarget trials at the Fz electrode site than inexperienced subjects. The amplitude differences were not statistically different between groups at the Pz electrode site but were significantly different at the Fz electrode site. Unfortunately, the potential confound of age was not controlled. Experience on the task was positively related to age; therefore, the variable of age is confounded with experience. It has been relatively well established that the aging process, in general, has an effect upon the amplitude and the distribution of electrical activity across electrode sites (Strayer, Wickens, & Braune, 1987; Pfefferbaum, Ford, Wenegrat, & Kopell, 1984). The amplitude of all components become somewhat attenuated and the distribution of electrical activity becomes very similar across electrode sites. However, most studies that have investigated the effects of aging on the ERP have used rather disparate age groups, including children and adolescents (Knight, 1987; Pfefferbaum et al., 1984; Smith, Michalewski, Brent, & Thompson, 1980). A study conducted to differentiate between the effects of experience and aging could be useful to determine if the ERP technique is a viable tool in the assessment of knowledge acquisition or training. The present study was designed to aid in differentiating and help delineate between the effects of aging and experience on ERP components.

Method

Subjects

Forty-eight U.S. Navy men (three groups of 16) were used as voluntary subjects. Group I (Young = YNG) was composed of sonar-inexperienced men ranging in age from 18 to 22 years (M = 19.2). They were selected for sonar duty on the basis of their performance on the Armed Services Vocational Battery (ASVAB). Although selected, YNG subjects had not yet received any sonar training. Group II (OLD) ranged in age from 28 to 40 years (M = 34.2), were not sonarmen, and did not have any sonar-related experience or training. The subjects for the OLD group were age-matched to the subjects in Group III. Group III (Experienced = EXP) ranged in age from 28 to 40 years (M = 32.5), were all trained sonarmen, and had at least four years of at-sea operational sonar experience.

All analyses were conducted using 48 subjects. The data from 23 additional subjects were not used. Six subjects were eliminated because their performance did not meet the minimum stated criteria. An additional 16 subjects did not have 30 acceptable target trials. The results of one subject was accidentally deleted from the computer.

Apparatus

An electroencephalogram (EEG) was recorded from two midline (Fz and Pz) sites and referenced to linked mastoids in accordance with the International 10-20 system (Jasper, 1958). EEG electrodes were Grass gold cup electrodes and were attached to the scalp with collodion. A gold cup electrode clipped to the left ear served as ground. Electrooculogram (EOG) was monitored by Beckman bio-potential electrodes. One electrode was placed 1 centimeter (cm) supra to the outer canthus of the left eye and one was placed 1 cm infra to the outer canthus of the right eye. Electrode impedances were kept below 5 kohms. Stimuli were generated by a Wavetek model 275 Programmable Arbitrary/Function Generator and were delivered through a Telephonics headset (TDH-39p). White noise was generated by a General Radio Company noise generator. EEG was collected and amplified by means of a Grass Model 12 Neurodata Acquisition System. Internal low frequency filters were set at .1 hertz (Hz) and high frequency filters were set at 30 Hz. EEG was recorded, averaged, and stored on a Digital VAX RT-Lab computer using a 250-Hz sampling rate. The recording epoch was 452 milliseconds (ms) with a 60-ms prestimulus baseline. Individual epochs were averaged for target and nontarget trials. The interstimulus interval was randomly varied from 850 to 1550 ms. To control eye movement, a black fixation cross (5 cm by 5 cm) on a white cardboard background was placed 76 cm directly in front of the subject. An on-line artifact rejection routine was used to eliminate any trial in which EEG activity exceeded 100 microvolts (µv) or EOG activity exceeded 45 µv.

Stimuli

Each subject completed a standard (90%/10%) auditory-discrimination oddball task, based upon differences in the frequency of the two tones. The stimuli were 2000 Hz and 750 Hz, 22 ms (2 ms ramp) tones presented at 70 Db SPL with a constant 50-Db white background noise. The nontarget stimulus was a 750-Hz tone and was presented on 90% of the trials. The target stimulus was a 2000-Hz tone randomly intermixed with the nontarget tones and presented on 10% of the trials. The task automatically terminated when 30 acceptable target trials (free of artifacts) and 270 acceptable nontarget trials had been recorded, or if the sum of the accepted and rejected trials exceeded 600 trials.

Procedure

The subjects were seated in a quiet room, and they listened to binaurally presented stimuli through headphones. Prior to the performance of each task, the subjects were allowed to practice the task for 60 trials. A sequence of targets and nontargets that differed from the sequence used in the experimental task was used for the practice trials. The subjects were instructed to: (1) focus on the center of the fixation cross; (2) avoid excessive eye blinks, and body and eye movement; and (3) to remember the number of times the target was detected. The behavioral responses from the practice trials were monitored to ensure that the subjects understood the task. The data from subjects who had, on both tasks, a minimum of 30 acceptable targets, 270 acceptable nontargets, and a minimum performance score of 70% were used for analysis. The ERP data were evaluated with multivariate analysis of variance (MANOVA; Vassey & Thayer, 1987).

Results

A Scheffe' multiple comparisons test of mean group ages revealed that YNG significantly differed from OLD and EXP ($p<.05$) and that OLD and EXP did not differ significantly ($p>.05$). The groups did not significantly differ on any of the demographic or accuracy measures.

Grand mean waveforms for each group (3), site (2), and stimulus (2) are shown in Figure 1. Here it can be seen that, in general, for the target stimuli, YNG has the largest amplitude at Pz and EXP has the largest amplitudes at Fz. OLD has amplitudes very similar to YNG for the frequency task at Fz but the smallest amplitudes at Pz.

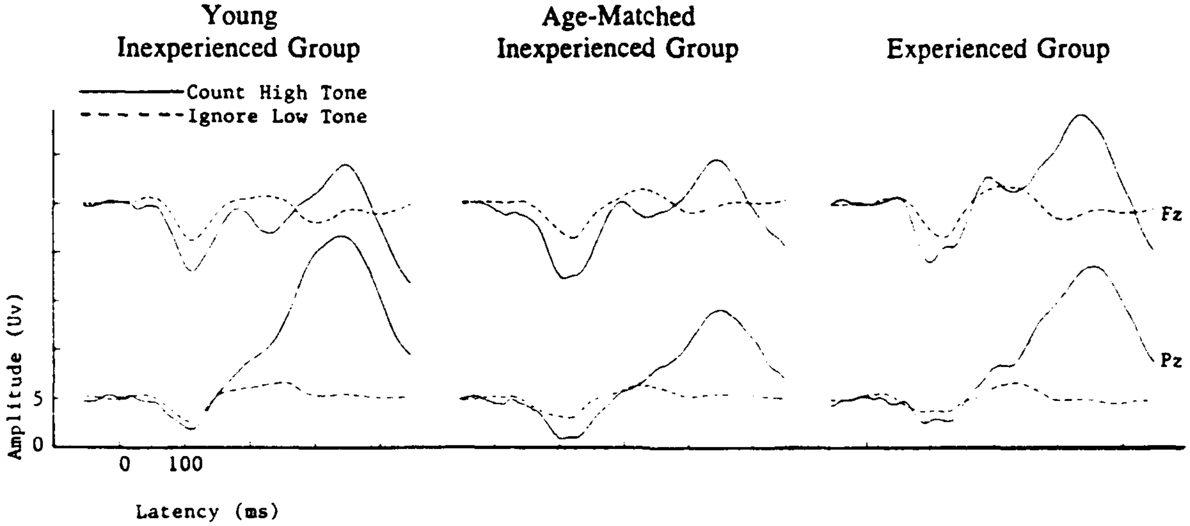

Figure 1. Grand mean waveforms for each group at sites Fz and Pz.

A three-way repeated-measures MANOVA (group [3] by site [2] by stimulus [2]) was performed on the amplitude and latency values for N1 (50 to 150 ms), P2 (150 to 250 ms), and P3 (250 to 452 ms). The amplitude and latency value for the N1, N1-P2 complex, P2, and P3, for each group, each site, and each of the stimuli are shown in Table 1. Additionally, a separate three-way repeated-measures MANOVA (group [3] by site [2] by stimulus [2]) was performed on the N1-P2, and a two-way MANOVA (group [2] x site [2]) was performed on the P2 latency and P3 amplitude difference values.

Table 1

Mean Component Amplitude and Latency for Each

Group, Site, and Stimuli

		N100			
Group	Site	Target		Nontarget	
		Amp	Lat	Amp	Lat
YNG	Fz	- 7.8	120	- 4.2	114
	Pz	- 4.6	101	- 2.6	105
OLD	Fz	- 8.9	111	- 4.2	113
	Pz	- 5.1	111	- 2.8	108
EXP	Fz	- 7.2	107	- 4.0	116
	Pz	- 4.2	110	- 2.2	110
		N1-P2			
YNG	Fz	10.4		5.7	
	Pz	12.5		4.8	
OLD	Fz	11.0		5.7	
	Pz	09.1		4.3	
EXP	Fz	12.5		6.3	
	Pz	09.9		4.3	
		P200			
YNG	Fz	2.6	195	1.6	208
	Pz	7.9	213	2.1	216
OLD	Fz	2.1	218	1.5	219
	Pz	3.9	232	1.6	220
EXP	Fz	5.3	212	2.2	216
	Pz	5.7	223	2.1	219
		P300			
YNG	Fz	05.8	338	1.3	319
	Pz	17.7	341	1.4	312
OLD	Fz	05.6	335	1.3	316
	Pz	10.1	345	0.7	299
EXP	Fz	10.7	335	1.1	293
	Pz	14.8	348	0.8	278

N1 Component

The analysis of the N1 amplitude data revealed a significant site effect ($F[1,45] = 86.25$, $p<.001$). This indicates that the amplitude of targets and nontargets is largest at Fz. A significant effect of stimulus was also found ($F[1,45] = 106.08$, $p<.001$). This indicates that the amplitude of the targets is larger than the amplitude of the nontargets (see Table 1). A significant Site by Stimulus interaction, $F(1,45) = 16.19$, $p<.001$, suggests that although target amplitude is, in total, significantly larger than nontarget amplitude the effect is site specific. The analysis of the N1 latency data showed a significant site effect ($F(1,45) = 6.65$, $p<.013$). The N1 latencies are longer at Fz for both stimuli.

N1-P2 Complex

The analysis of the N1-P2 complex data revealed a significant site effect, $F(1,45) = 8.40$, $p<.006$, and Group by Site interaction, $F(2,45) = 4.82$, $p<.013$. N1-P2 amplitudes are larger at Fz regardless of stimulus or group. Although the between-group comparisons were not significant, the group means suggest that the Group by Site interaction was due to the EXP group's larger amplitudes at Fz and the YNG group's larger amplitudes at Pz. The analysis also showed a stimulus effect, $F(1,45) = 104.20$, $p<.001$, and a Group by Site by Stimulus interaction, $F(2,45) = 3.54$, $p<.037$. The stimulus effect suggests that, regardless of site and group, the targets are larger in amplitude than the nontargets. The Group by Site by Stimulus interaction suggests that the difference between stimuli varies as a function of recording site. An analysis of the N1-P2 amplitude difference values (N1-P2 for targets minus N1-P2 for nontargets) for the frequency task showed a significant Group by Site effect, $F(2,45) = 3.54$, $p<.037$. This indicates that the values are larger at Fz for OLD and EXP while they are larger at Pz for YNG.

P2 Component

The analysis of the P2 amplitude data revealed a main effect of site, $F(1,45) = 9.26$, $p<.004$, a Group by Site interaction, $F(2,45) = 3.52$, $p<.038$, and a *Site by Stimulus* interaction, $F(1,45) = 10.88$, $p<.028$. The frequency task also showed a main effect of stimulus type, $F(1,45) = 25.08$, $p<.001$. The site effect indicates that the amplitudes, regardless of stimulus, are larger at the Pz site. The Group by Site effect indicates that EXP has larger amplitudes at Fz whereas YNG has larger amplitudes at Pz. The Site by Stimulus interaction indicates that the stimuli are differentially larger at both sites. The stimulus effect indicates that, overall, the targets have larger amplitudes than the nontargets. An overall significant group difference was found between OLD and YNG, $F(1,30) = 5.56$, $p<.05$. A between-group comparison was significant for target P2 amplitudes which differed significantly at Pz, $F(1,30) = 4.50$, $p<.05$, for EXP and OLD and, $F(1,30) = 6.75$, $p<.05$, for YNG and OLD. Analysis of the P2 latency data showed a significant effect of site, $F(1,45) = 8.64$, $p<.005$. Overall, latencies were longer at Pz.

P3 Component

Analysis of the P3 amplitude data showed a significant site effect, $F(1,45) = 62.43$, $p<.001$, a Group by Site interaction, $F(2,45) = 9.27$, $p<.004$, a stimulus effect, $F(1,45) = 215.37$, $p<.001$, a Site by Stimulus interaction, $F(1,45) = 57.44$, $p<.001$, and a Group by Site by Stimulus interaction, $F(2,45) = 7.11$, $p<.002$. Concerning the site effect, a higher amplitude was found at Pz regardless of stimulus type. YNG has the larger amplitude at Pz and EXP the largest amplitude at Fz. The amplitudes of the targets are significantly larger than the nontargets which is revealed in the significant stimulus effect. The Site by Stimulus interaction shows that amplitude varies as a function of recording site. The Group by Site by Stimulus interaction indicates that the difference between the amplitudes of the stimuli varies as a function of group and site. Additionally, a significant group effect was found, F(2,45) = 5.81, p<.006. Therefore, an analysis of the P3 amplitude difference was performed. Three one-way MANOVAs were performed on the P3 amplitude differences in order to locate the group main effect. The results of the one-way MANOVAs showed that YNG differed significantly from OLD at Pz, F(1,30) = 16.19, p<.05, but not at Fz. YNG differed significantly from EXP at Pz, F(1,30) = 5.21, p<.05, but not at Fz. OLD differed significantly from EXP at Pz, F(1,30) = 18.96, p<.05, and at Fz, F(1,30) = 6.56, p<.05.

Analysis of the P3 latency data showed a significant stimulus main effect, F(1,45) = 15.89, p<.001. An examination of the means indicates that the target latencies are significantly longer.

To assess the relationship between P3 amplitude distribution and age, target amplitude at Fz was subtracted from target amplitude at Pz (see Strayer et al., 1987). The results were then correlated with the subjects' ages. The results (r = -.58, p<.001) are similar to those reported by Strayer et al. (r = -.56, p<.001) and indicate that the Pz - Fz difference decreases significantly as a function of age. Our data suggest that the negative correlation may reflect more of a change in Pz component amplitude because the amplitude of the Pz component decreases with age and thus becomes more similar to Fz component amplitude. Within-group zero order correlations and partial correlations were performed to further evaluate the effect of age and experience on the Pz - Fz difference. The results of these analyses are shown in Tables 2 and 3. These data indicate that, although both age and experience are related to the Pz - Fz difference, there is an effect due to experience that is unrelated to age.

Table 2

r for Pz - Fz With Age and Sonar Experience Within Each Group

Group	r (Age)	p	r (Sonar Experience)	p
YNG	-.41	.057		
OLD	-.14	.295		
EXP	-.56	.012	-.64	.004

Table 3

Partial Correlations for Pz - Fz by Age and Sonar Experience for EXP

Zero Order Correlation:

	Age	p
Sonar Experience	.50	.025

	Controlling for Sonar Experience:		Controlling for Age:	
	Age	p	Sonar Experience	p
Pz - Fz	-.36	.091	-.51	.027

Discussion

Previous studies have suggested that sonar operators, through experience, may develop an altered cognitive strategy for discriminating target and nontarget stimuli and that this altered strategy may be reflected in a different scalp distribution of brain electrical activity. They suggested that their results may represent differences between automatic and controlled processes (Kobus et al., 1987, 1988). Although the efficiency of automatic processes occurs along a continuum wherein the consistency of response mapping determines improvements in performance (Schneider & Fisk, 1982), it would seem that sonar operators gain experience with a low-level form of response mapping. Distractors, which initially appear to be targets, are frequently encountered by sonarmen and therefore are not responded to with a high level of consistency. Aberrant signals, on the other hand, which may be targets, are evaluated over a period of time, auditorily and visually. Unless the myriad possible auditory target stimuli that sonarmen are exposed to become part of long-term memory store, they are probably not using an automatic form of cognitive processing (Shiffrin & Schneider, 1977). It would seem more plausible that when sonarmen encounter a deviant stimulus they become more attentive, and evaluative processes are initialized. The present data would seem to support such a hypothesis because the experienced group's N1-P2 complex and P3 component were larger than the older inexperienced group at both sites. Additionally, the experienced group's N1-P2 complex and P3 amplitude were largest at Fz among all groups. The N1-P2 complex appears to be related to attention (Hillyard & Kutas, 1983) and P3 to the strength of stimulus response mapping (Rosler, 1981).

Rather than using an automatic form of processing the experienced group's larger P3 amplitude at Fz would suggest that they are using a comparatively more controlled form of processing. Rosler found that during initial training the amplitude of P3 was larger, and during the final stages of training it was attenuated. Klein et al. (1983) found that P3 was missing or greatly reduced for music students who were thought to be using an automatic form of processing. Generally, P3 amplitude has been suggested to be an indicator of cognitive capacity allocation (Donchin, Kramer, & Wickens, 1986; Israel, Chesney, Wickens, & Donchin, 1980).

P3 amplitude, to stimuli in a primary task, is reduced as the level of difficulty of a secondary task is increased. Finally, subjective importance of attention in sonar operations was confirmed by Kobus and Lewandowski (1992) in a survey of 538 sonar operators wherein most listed "attention ability" as the factor most critical to sonar operation.

The young, inexperienced group had higher P3 target amplitudes at Pz, which indicates that age had an effect on the ERP in the present study. The higher target P3 amplitudes at Pz are moderately but significantly correlated with age. These results are similar to previous studies that have found a parietal target P3 distribution in young subjects and a frontal distribution in older subjects (Knight, 1987; Pfefferbaum et al., 1984; Strayer et al., 1987). No significant correlation was found for P3 latency and age as had been found in previous studies (Goodin, Squires, Henderson, & Starr, 1978; Barrett, Neshige, & Shibaski, 1987). Pfefferbaum et al. (1984) and Smith et al. (1980) have reported that the target P3 is parietally distributed in the young subjects and is uniformly distributed in older subjects. The present study shows that the target P3 was larger at Pz for all age groups, however, the P3 was attenuated at Pz in the older, inexperienced subjects and comparatively larger at Fz. This distribution also seemed to be influenced by experience because the experienced group displayed the largest mean amplitude at Fz. These results are in agreement with Pfefferbaum et al. (1984) and Smith et al. (1980) who found similar age group differences. However, their age groups were much more disparate than the groups in the present study. The present study used groups of subjects that were that much younger and closer in age than those used in previous studies. We found that age-related ERP differences occur at a much younger age than reported elsewhere.

Although the N1-P2 results were similar to those obtained by Kobus et al. (1987), the older, inexperienced group's amplitudes were not significantly different from those of the experienced group. Since no N1 amplitude group main effect or interactions were found, the N1-P2 results may be attributable to differences in the amplitude of P2. The distribution of the N1-P2 complex is controversial; however, it has been suggested that it is generated in the association areas of the frontal cortex (Nataanen & Picton, 1987).

Kobus and associates' finding that the experienced group's P2 target and nontarget amplitudes were largest at Fz while the inexperienced group's amplitudes were largest at Pz was not replicated. The experienced group did, however, have the largest target amplitudes at Fz. A significant difference was found between the older, inexperienced group and the experienced group for the P2 amplitude data. Rather than differences in scalp distribution, as found by Kobus et al., the present results suggest that the sonar-experienced group may have been more attentionally focused than older, sonar-inexperienced group and this attentional focus was reflected in a greater overall P2 amplitude (Hillyard & Picton, 1979). Hillyard and Picton (1979) and Lindholm and Koriath (1985) have suggested that P2 amplitude is larger for an attended stimulus than it is for an ignored stimulus.

The P2 latency group interactions found by Kobus et al. were not confirmed in the present study. The site effect we found shows that, across groups, P2 latency was longer at site Pz than at Fz. Combined with the P2 amplitude analysis, these results show that latency and amplitude were, overall, largest at site Pz. A post-hoc MANOVA, conducted on the P2 data for the experienced group and the older, inexperienced group, found no significant site effect. Therefore, it appears that the young, inexperienced group accounts for the variation in site amplitudes. This would suggest that the older subjects had a uniform distribution of P2 amplitude while the young subjects had larger amplitudes at Pz. Smith et al. (1980) have previously reported a uniform P2 distribution for older subjects (M age = 71.1) and a parietal distribution for young subjects (M age = 21.3).

The sonar-experienced group had a larger P3 response at site Fz. The experienced group had an overall larger response, at both sites, than the older inexperienced group and the largest response, for all groups, at Fz. Previous studies that have focused on P3 as an index of automatic versus controlled processing suggest an attenuation of P3 amplitude with automaticity (Rosler, 1981; Klein et al., 1983). Such results would predict comparatively smaller P3 amplitudes for target tones for the experienced group if they were using an automatic form of cognitive processing. However, the experienced group's P3 amplitudes were larger than those of the older inexperienced group at both sites and larger than the young, inexperienced group at site Fz.

There is a need to further study and to more accurately gauge the effect of sonar experience on the auditory ERP. The present study and the Kobus studies used tasks that were not sufficiently difficult to allow possible behavioral score differences to emerge. An important question that needs to be answered is whether experienced subjects are better at detecting deviant stimuli and if such a difference exists, can it be measured behaviorally. Also, a question remains as to whether this effect is confounded with experience and whether a difference can be observed in response latencies. In future studies it would be more prudent to use a recording epoch of about 1000 ms to capture the peak P3 activity for all the subjects.

The question of whether experienced sonarmen are better able to maintain an attentional focus still needs to be answered. A study that controls for task and session which approximate the length of a normal watchstanding period may help to resolve this question. Finally, automatic and controlled processing in experienced sonar operators may be better measured in a dual-task paradigm. If experienced operators are using an automatic form of processing, a decrement in performance with the addition of a second task would not be expected but should compromise the performance of inexperienced subjects (Schneider & Shiffrin, 1977).

Our results suggest that experience and age have an effect on ERP component amplitude and distribution. The results concerning age and ERPs, support and extend the results of previous studies. Although attentional and stimulus evaluation processes have been heretofore linked to ERP component parameters, our study found that they may be enhanced with real-world task experience. ERP studies should control for the possible confounds of task experience and age.

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Sonar operators listen to and interpret complex auditory signals for thousands of hours over a period of years. They develop an expertise in tone discrimination that could be expected to influence how they process auditory information, which would change their task-related brain electrical activity. The evidence thus far suggests that the brain electrical activity of experts is different from that of novices. Experts may be of different ages and several studies have shown that ERPs change with aging. Therefore, the affect of sonar experience and age on auditory ERPs was investigated.

The results reported, concerning age and ERPs, support and extend the results of previous studies. Although other experience-related ERP studies found that various components and distributions were related to task experience their results were not supported.

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