Interindividual differences in the diurnal variation of the human auditory evoked potential

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During sessions at 4 a.m., 10 a.m., 4 p.m., and 10 p.m., measurements were taken of the auditory AEP following the onset of a burst of white noise. For all subjects, a significant time-of-day fluctuation of the N105-P194 amplitude was found. The time of day at which the maximal value was recorded, however, appeared to vary with the subject's score on a morningness/eveningness questionnaire. Moderately morning-type subjects attained their maximal values at 10 a.m., while subjects with an intermediate score reached their largest amplitude value at 4 p.m.

The diurnal variation of various physiological and performance variables is most commonly held to be a manifestation of a diurnally fluctuating level of arousal (cf. Colquhoun, 1971; Fröberg, 1975). Therefore, the intraindividual stability of the averaged evoked potential (AEP) recorded at different times of day should not be taken for granted. The N1-P2 complex, in particular, appears to be amenable to the effects of arousal, as suggested by the influence of changing levels of vigilance (cf. Fruhstorfer & Bergström, 1969). With regard to the diurnal stability of the auditory AEP, Heninger, McDonald, Goff, and Sollberger (1969) found no difference between measurements at 7-9 a.m. and at 4-6 p.m. In a recent study, however, Browman (1979) did record a larger N100-P200 amplitude for an 11 a.m. session than for a 9 p.m. session. It is not clear to what extent the deviating times of his measurements have influenced these results. As a tentative explanation of the absence of a diurnal effect in Heninger's study, Browman suggests that account was not properly taken of interindividual differences in sleep duration and wake-up time. There are indications of the existence of reliable interindividual differences in the diurnal variation of various physiological variables, in particular between habitually morning-active (M-type) and habitually evening-active (E-type) subjects. Pátkai (1971a, 1971b, Note 1) reports interactions between diurnal type and time of day with regard to body temperature, adrenaline excretion, and subjective alertness. Under conditions of sleep deprivation, however, negative results have been found (Fröberg, 1977). Diurnal differences between M-type subjects and E-type subjects with regard to the visual and auditory N1-P2 amplitude of the AEP have also been reported. Kerkhof, Korving, Willemse-v.d. Geest, and Rietveld (1980) have shown that the direction of amplitude change between measurements at 8:30 a.m. and

8 p.m. is dependent upon the subject's score on a morningness/eveningness questionnaire. M types attained a significantly larger amplitude in the morning than in the evening, while E types showed the reverse. In order to obtain additional information on this topic, the data of a previous study (Kerkhof, in press) were reanalyzed. These data had been collected during sessions at times (4 a.m., 10 a.m., 4 p.m., and 10 p.m.) which corresponded fairly well with those of both Heninger's and Browman's studies. Of the original 12 subjects, three moderately M types were compared to three subjects (I types) with a score intermediate between those of M types and those of E types.

METHOD

Subjects

On the basis of a translated version of the morningness/eveningness questionnaire of Horne and Östberg (1976), 3 moderately M types (1 female) and 3 I types (3 females) were selected from the 12 subjects (aged 20-31) of the Kerkhof (in press) study. They were asked to refrain from any activity that might disturb their habitual sleeping-waking pattern for at least 3 days preceding the experiment. During the periods between the experimental sessions, the subjects adhered to their habitual activities as much as possible, but stayed in the laboratory, where food, drink, and sleeping facilities were provided.

Procedure

During a signal detection task, the subjects were presented with 2.2-sec bursts of wide-band white noise (65 dB SPL) with random intervals of between 9 and 14 sec. After termination of the noise, the subject pushed a button in response to the presence or absence of a weak signal, occurring 900 msec after noise onset. Thus, noise onset served as a warning signal for the subsequent observation interval within which a signal might occur. In this paper, data will be presented on the AEP following noise onset. The AEP data were collected in a round-the-clock experiment, which consisted of four successive sessions, each at a different time of day (3:15-4:45 a.m., 9:15-10:45 a.m., 3:15-4:45 p.m., 9:15-10:45 p.m.). One session was made up of three blocks of 60 trials each. The

time of day at which the subject started the experiment was balanced over subjects.

The stimuli were generated by a HP 8057 A noise generator and delivered through Sennheiser HMD 110 earphones.

Recording and Analysis

The electroencephalogram (EEG) was recorded with Ag/AgCl disk electrodes (Fz, C3, Cz, C4, Pz), referred to the right mastoid and amplified by Grass 7P511 amplifiers (50% amplitude at .1 and 100 Hz). In the same way, the electrooculogram (EOG) was recorded with Ag/AgCl electrodes placed just above and below the right eye. In the event of EEG overflow and/or excessive EOG activity, a trial was discarded with replacement. Sampling (166 points/sec) and analog-to-digital conversion, as well as stimulus presentation and response registration, were controlled by a PDP 11/10 computer. Off-line, on a PDP 11/45 computer, the EEG epochs of each session were averaged according to a subject's responses. From these averages, one waveform was selected, that is, the one that was based on the largest number of EEG epochs (about 35).

The analyses of variance (ANOVA) were carried out on the basis of a split-plot design (Kirk, 1968). Pairwise comparisons were made with Tukey's HSD statistic (cf. Kirk, 1968).

RESULTS

Figure 1 shows examples of AEP waveforms for one M-type subject and one I-type subject. Peak-to-peak measurements were taken of the first negative (N1) and the following positive (P2) peaks. Their mean latencies to noise onset were 105 and 194 msec, respectively. These peaks will further be referred to as N105 and P194. For the two groups of subjects separately, the amplitude values averaged over subjects and leads have been plotted as a function of the time of their recording in Figure 2. ANOVA of the N105-P194 values for the two groups of subjects, five leads, and four sessions showed a significant effect of time of day [$F(3,12) = 4.10$, $p < .05$]. There was a trend, however, of an interaction between diurnal type and time of day [$F(3,12) = 2.49$, $p = .11$]. Tests for simple effects gave evidence of a difference between the two groups for the 10 a.m. session

Figure 1. Auditory AEPs (Cz) of one M-type subject and one I-type subject for four times of the day. Stimulus onset coincides in time with the beginning of the trace. A baseline has been drawn at the level of the mean 100-msec prestimulus EEG activity.

Figure 2. N1-P2 amplitude values averaged over subjects and leads for M-type (dashed line) and I-type (solid line) subjects as a function of the time of their recording.

[$F(1,80) = 4.66$, $p < .05$]. From pairwise comparisons, it appeared that for M types the 10 a.m. session attained a larger amplitude value than did the 10 p.m. session ($p < .05$). For the I types, the 4 p.m. value proved larger than the 4 a.m. and the 10 p.m. values ($p < .05$).

These results were consistent across leads, since no interaction was found between leads and time of day and/or subjects. The main effect of leads proved significant [$F(4,16) = 28.98$, $p < .01$] and showed a scalp distribution with a frontal maximum and successively smaller amplitudes of the central and parietal electrode sites.

These results confirm the existence of a significant time-of-day fluctuation of the auditory N105-P194 amplitude for all subjects; but they also indicate that the time of day at which the maximal amplitude is recorded varies with the subject's position on the morningness/eveningness scale. For the latency values of the two peaks, no time-of-day effects were found.

DISCUSSION

The present study provides additional information about interindividual differences in the diurnal variation of the auditory AEP in that it shows that less extreme diurnal types such as moderately morning types and intermediate types can also be differentiated on the basis of the N105-P194 amplitude value they record at different times of day. In combination with already existing evidence (Kerkhof et al., 1980), these results substantiate the notion that the classification of subjects in terms of morningness/eveningness explains a significant part of the error variance in diurnal studies. Failure to take these interindividual differences into account thus could easily allow diurnal response patterning to go unnoticed. The question of how far this can be generalized to other neurophysiological parameters remains a subject for further study.

These results also offer an explanation of the early maximum of the N100-P200 amplitude in Browman's study (1979). He mentions that, for the duration of the study (8 days), all three subjects had a wake-up time of 7 a.m. following 8 h of sleep. On the assumption that these times correspond to their habitual sleeping-waking pattern, they can be tentatively characterized as M types. Similarly, it would be interesting to know if the afternoon maximum of the P100 and P200 amplitudes of the somatosensory evoked potential in the study of Davis, Buchsbaum, and Bunney (1978) is related to a relative preponderance of I-type subjects in their samples.

The diurnal covariation of self-rated alertness, body temperature, and the N105-P194 amplitude suggests the nonspecific influence of intraindividual fluctuations of the tonic level of arousal (cf. also Colquhoun, 1971). Studies within the context of selective attention and habituation (cf. Picton, Hillyard, & Galambos, 1976) have shown that the N105-P194 amplitude can also be influenced by more phasic processes. The question of how far these effects are common manifestations of independently operating processes or how much they reflect the net outcome of interacting processes requires further study. For example, a diurnal study of habituation could determine whether the diurnal variation of the N105-P194 amplitude is caused by a time-varying habituation process or not.

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