Title
Stimulus frequency and masking as determinants of P300 latency in event-related potentials from auditory stimuli

Journal
Biological Psychology, 21(4)

ISSN
0301-0511

Authors
Polich, John
Howard, Lawrence
Starr, Arnold

Publication Date
1985-12-01

DOI
10.1016/0301-0511(85)90185-1

Biological Psychology 21 (1985) 309–318
North-Holland

STIMULUS FREQUENCY AND MASKING AS DETERMINANTS OF P300 LATENCY IN EVENT-RELATED POTENTIALS FROM AUDITORY STIMULI *

John POLICH

Department of Neurology, California College of Medicine, University of California, Irvine, CA 92717, U.S.A.

Lawrence HOWARD

School of Social Sciences, University of California, Irvine, CA 92717, U.S.A.

Arnold STARR

Department of Neurology, California College of Medicine, University of California, Irvine, CA 92717, U.S.A.

Accepted for publication 8 May 1985

The effects of target tone frequency, presence of a masking stimulus, and subject sex on the auditory ERP were studied with an 'oddball' paradigm. P300 latency became shorter (about 15 msec) as the difference between the standard (1000 Hz) and target tone frequency increased (1500, 2000, 4000 Hz) but became longer (about 10 msec) with the presence of a white noise masking stimulus. Similar results were obtained for both the P3a and P3b subcomponents of the P300 potential. No significant differences between the adult male and female subjects were observed. The role of stimulus parameters in applied testing situations is discussed.

1. Introduction

The P300 component of the event-related brain potential (ERP) is a large (5–15 μV), positive-going waveform that occurs with a modal latency of about 300 msec in normal young adults. Although the neurophysiology underlying the P300 is still being explored (Halgren, Squires, Wilson, Rohrbaugh, Bab and Crandall, 1980; Okada, Kaufman and Williamson, 1983), the cognitive events associated with its generation have received considerable attention (Donchin, 1981; Donchin, Ritter and McCallum, 1978; Pritchard, 1981). Because the

* The authors wish to thank Beverly Henderson for help in data collection and Gary Carter of the Nicolet Instrument Company for providing the equipment. This research was supported by NIH Grant NS 11876. Address correspondence to: John Polich, Preclinical Neuroscience, Scripps Clinic and Research Foundation, 10666 N. Torrey Pines Road, La Jolla, California, 92037, U.S.A.

0301-0511/85/$3.30

P300 is thought to reflect stimulus evaluation and classification processes, it has found application in the assessment of cognitive function. In particular, its peak latency has been used to evaluate the effects of aging on cognition (Brown, Marsh and LaRue, 1983; Ford, Duncan-Johnson, Pfefferbaum and Kopell, 1982; Goodin, Squires, Henderson and Starr, 1978; Howard and Polich, 1985; Pfefferbaum, Ford, Roth and Kopell, 1980; Pfefferbaum, Ford, Wenegrat, Roth and Kopell, 1984; Picton, Stuss, Champagne and Nelson, 1984; Polich, Howard and Starr, in press; Smith, Michalewski, Brent and Thompson, 1980; Squires, Goodin and Starr, 1979; Syndulko, Hansch, Cohen, Pearce, Goldberg, Montan, Toutellotte and Potvin, 1982), as well as neurological and psychiatric disorders affecting mental functions (Brown, Marsh and LaRue, 1982; Canter, Hallett and Growdon, 1982; Goodin, Squires and Starr, 1978; Hansch, Syndulko, Cohen, Goldberg, Potvin and Tourtellotte, 1982; Litzelman, Thompson, Michalewski, Patterson and Bowman, 1980; Pfefferbaum et al., 1984; Polich, Ehlers, Otis, Mandell and Bloom, in press; Squires, Chippendale, Wrege, Goodin and Starr, 1980; Squires, Galbraith and Aine, 1979). Thus, P300 latency as an index of cognitive function is becoming an important and widespread tool in the assessment of mental capability.

A typical procedure employed in these investigations involves the presentation of two different signals, one less frequently than the other. The subject keeps a mental count or presses a button to the infrequent event and thereby discriminates the target stimulus from the background standard stimulus events. This so-called 'oddball' paradigm reliably produces the P300 component and has often been used to study factors which affect its amplitude (e.g. Duncan-Johnson and Donchin, 1977; Squires, Wickens, Squires and Donchin, 1976). The latency of the P300 has also been examined, typically by means of complex task situations involving visual stimuli (e.g. Kutas, McCarthy and Donchin, 1977; Duncan-Johnson and Kopell, 1981; McCarthy and Donchin, 1981; Polich, McCarthy, Wang and Donchin, 1983), with only a few studies using a simple auditory stimulus paradigm and reporting some normative latency data (e.g. Ford, Hink, Hopkins, Roth, Pfefferbaum and Kopell, 1979; Polich, Howard and Starr, 1983; Squires, Donchin, Squires and Grossberg, 1977). However, variations in the application of the oddball counting task may have produced some of the latency variability obtained across these studies, because differences in stimulus parameters could readily contribute to P300 latency by affecting the ease of stimulus categorization (Goodin, Squires and Starr, 1983; Fitzgerald and Picton, 1983; Magliero, Bashore, Coles and Donchin, 1984). To assess this possibility, the present studies employed an auditory oddball paradigm in which the frequency separation between the target and standard tone was varied in order to manipulate stimulus discriminability. Each stimulus tone frequency condition was also presented with and without a white noise background; this technique is often used to mask environmental sounds during ERP recording and may also affect task difficulty (cf. McCarthy and Donchin, 1976; Squires, Donchin, Herning and McCarthy, 1977). In addition, subject sex, which affects the latencies of various sensory evoked pontentials (e.g. Polich and Starr, 1983; Shucard, Shucard and Cummings, 1981; Stockard, Stockard, and Sharbrough, 1978), was controlled.

2. Methods

2.1. Subjects

A total of 24 volunteer subjects (12 of each sex) who ranged in age from 18–35 years were obtained from within the university community. All reported normal hearing and participated in one two-hour session.

2.2. Recording conditions

ERPs were elicited by presenting subjects with a series of binaural tones at 60 dB nHL with a 9.9 msec rise/fall and 50 msec plateau time. The tones were presented in a random sequence with the standard tone occurring 80% of the time and the target tone 20% of the time at a rate of 1.1/sec. Subjects were instructed to keep a silent count of the number of target tones (as defined below). Stimuli were presented until a block of 200 artifact-free trials was obtained for each condition. Electroencephalographic activity (EEG) was recorded between the vertex (Cz electrode site in the 10–20 system) referenced to linked mastoids with a forehead ground. The filter bandpass was 1–30 Hz (3 dB down, 12 dB/octave slope). Although not optimal, the relative latency of the P300 should be unaffected by this bandpass range even though component amplitude would be reduced compared to a longer time-constant (see Duncan-Johnson and Donchin, 1979; Polich et al., 1983). The EEG was digitized at 3 msec/point for 768 msec and averaged on line by a Nicolet CA-1000 that also controlled the stimulus presentation and automatic artifact rejection of the averaged channel. Trials on which the EEG exceeded $\pm 45\ \mu V$ were automatically rejected and not included in the averaged waveform. Hence, only trials uncontaminated by eye blinks, eye movements, and muscle contractions that usually produce very large voltage fluctuations (typically greater than 100 μV) were recorded. Separate averages for the rare and frequent stimulus tones were plotted, with the latencies of the components defined at their peak or trough. Amplitudes were not measured.

2.3. Design and procedure

Subjects were placed in a sound-attenuating booth and instructed about the various stimulus conditions and the counting task. Each subject was then presented with six different stimulus conditions. The frequent or standard tone was always 1000 Hz, whereas the rare or target tone was 1500, 2000, or 4000 Hz. These frequencies were chosen to ascertain the effects of target and standard frequency separation on P300 latency over a reasonable but practical range. Each combination of tones was presented with a masking stimulus of 60 dB nHL white noise (MASKED) or without a masking stimulus (CLEAR). The presentation order of the six conditions was block randomized across subjects. After each experimental condition, the subject's count of the number of target tones was obtained, and s/he was given a brief rest period before the next condition.

3. Results

3.1. Count task data

Because the computer accepted only trials on which the EEG was within 50 μV of baseline, the number of trials each subject received varied for a given condition. An overall mean of 41.6 target tones was presented for each condition, but no statistical difference between the various conditions or subject groups was obtained ($F < 1$, for all main effects). Subjects were highly accurate in their target tone counts, missing the correct number on the average by 1.2 counts. No differences between any of the stimulus conditions or subject groups was obtained for the number of tones incorrectly counted or for the percentage of errors. It can be safely assumed, therefore, that subjects were sufficiently engaged by the task situation to produce accurate and consistent performance under all conditions.

3.2. Waveform data

Examples of the ERP data for all conditions are presented in fig. 1. These data are from four representative subjects and illustrate the potentials obtained for the six different conditions to both the rare (1500, 2000, and 4000 Hz) and frequent (1000 Hz) stimuli. The components are labelled in the middle two rows of the CLEAR stimulus condition and agree in morphology and latency range with previous reports. In most of the subjects, the P300 component from the target stimulus displayed two distinct subcomponents. These are labelled the P3a and P3b, with the former defined as the first positive-going potential occurring after the N2 between 220–280 msec, and the latter as the subsequent positivity occurring between 250–350 msec. Most often a bifurcated peak was observed for the same subject in the majority of recording conditions. If only a single positive peak was observed, it was labelled a P3b. While scalp distributions of these subcomponents could not be obtained, use of latency window

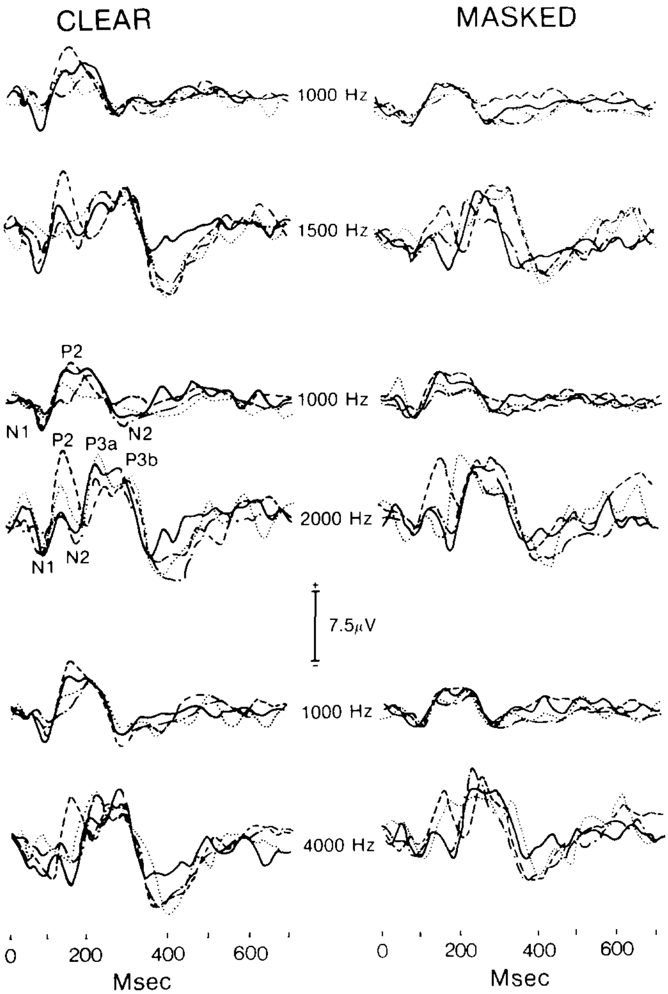

Fig. 1. Waveforms obtained from four different subjects (overplotted) for the standard (1000 Hz) and target tones (1500, 2000, 4000 Hz) in an auditory oddball paradigm. The CLEAR column illustrates waveforms collected when stimuli were presented without an auditory mask, while the MASKED column illustrates waveforms collected when stimuli were presented with a 60 dB white noise mask. Note the latency shift apparent in the P3a and P3b portion of the waveforms as a function of target tone frequency.

criteria and observation of the two subcomponents over task conditions within a subject facilitated component measurements and yielded similar results as those previously reported for the P3a and P3b varieties of the P300 potential (Ford, Roth and Kopell, 1976; Polich et al., 1983; Roth, 1973; Snyder and Hillyard, 1976, Squires, Squires and Hillyard, 1975).

Table 1
Mean latency (msec), standard deviation (SD), and number of subjects (N) demonstrating a P3a and P3b subcomponent in each stimulus condition

		1500 Hz		2000 Hz		4000 Hz	
		P3a	P3b	P3a	P3b	P3a	P3b
CLEAR	Mean	262	330	254	320	247	312
	SD	15.1	22.9	31.7	29.7	24.1	23.7
	N	22	24	21	24	22	24
MASKED	Mean	270	337	259	331	257	321
	SD	13.6	25.8	30.1	29.1	21.4	27.2
	N	22	24	22	24	23	24

The mean latencies and standard deviations of the P3a and P3b components from the target tone stimulus are presented in table 1 with the effects of task conditions illustrated in fig. 2. There was no statistical difference in the number of subjects yielding a P3 subcomponent across experimental conditions ($\chi^2 = 0.01$, $p > 0.9$), implying that the occurrence of a P3a and P3b was unrelated to the frequency of the target tone or the presence of a masking stimulus. As indicated by figs. 1 and 2, the P300 component complex occurred

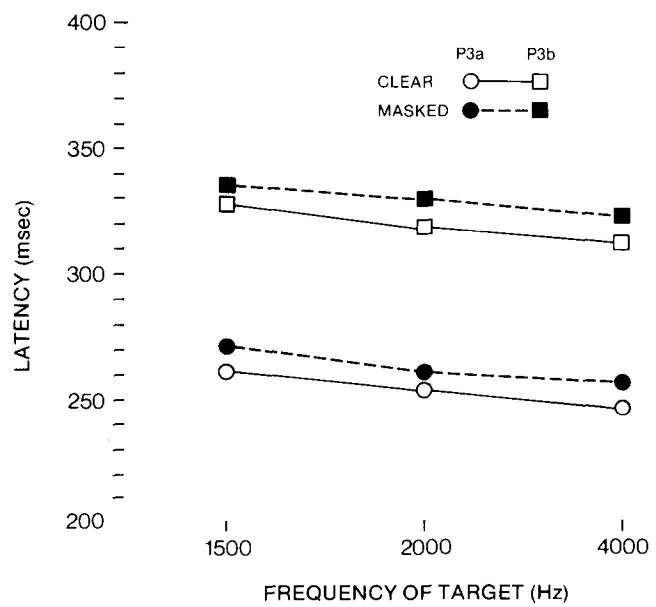

Fig. 2. Mean P3a and P3b latency as a function of target tone frequency for the CLEAR and MASKED stimulus presentation conditions.

at shorter latencies as the difference between the standard and target tone frequencies increased. Some slowing of the P300 components also appears to occur when the white noise masker was presented compared to the clear condition.

The latencies of each subcomponent were subjected to a four-factor (Target Frequency × Masking Condition × Component Type × Subject Sex) analysis of variance. The mean latencies for the P3a component were used as data points for the few subjects not yielding such measures in a specific condition. This analysis confirmed the trends indicated above: As the target tone frequency increased, P300 latency decreased significantly ($F(2,44) = 12.7$, $p < 0.0001$) although the magnitude of effect was only about 15 msec. The presence of a white noise masking stimulus significantly delayed the latency of the P300 component(s) by about 10 msec ($F(1,22) = 5.4$, $p < 0.03$). The latencies of the P3a and P3b were also different ($F(1,22) = 474.1$, $p < 0.0001$). None of these variables were affected by subject gender ($p > 0.4$, in all cases), and no significant interactions were obtained.

4. Discussion

Changing the target tone frequency relative to the standard tone and use of a white noise masking stimulus produced consistent, albeit small effects on P3a and P3b latency (10–15 msec). No differences in latency were observed as a function of gender. In applied testing, the choice of auditory stimulus parameters should not greatly affect overall P300 latency. However, if the perceptual difference between the target and standard tones is very small so that discrimination between the two tones is relatively difficult, the latency of the P300 can increase by up to 50 msec (Ford et al., 1979; Goodin et al., 1983; Squires, et al., 1980). Hence, variations in stimulus parameters is important insofar as they help determine task discrimination difficulty and therefore affect the resulting P300 peak latency for a given population. The present results illustrate the range of these effects for values of typically employed auditory stimuli and indicate that subject sex does not critically affect latency of the P300 ERP component.

References

Brown, W.S., Marsh, J.T. and LaRue, A. (1982). Event-related potentials in Psychiatry: Differentiating depression and dementia in the elderly. Bulletin of the Los Angeles Neurological Societies, 47, 91–107.

Brown, W.S., Marsh, J.T. and LaRue, A. (1983). Exponential electrophysiological aging: P300 latency. Electroencephalography and Clinical Neurophysiology, 55, 277–285.

Canter, N.L., Hallett, M. and Growdon, J.H. (1982). Lecithin does not affect EEG spectral analysis or P300 in Alzheimer's disease. Neurology, 32, 1260–1266.

Donchin, E. (1981). Surprise! ... Surprise? Psychophysiology, 18, 493–513.
Donchin, E., Ritter, W. and McCallum, C. (1978). Cognitive psychophysiology: The endogenous components of the ERP. In: Callaway, E., Tueting, P. and Koslow, S. (Eds.). Brain Event-Related Potentials in Man. Academic Press: New York, 349–411.
Duncan-Johnson, C.C. and Donchin, E. (1977). On quantifying surprise: The variation in event-related potentials with subjective probability. Psychophysiology, 14, 456–467.
Duncan-Johnson, C.C. and Donchin, E. (1979). The time constant in P300 recording. Psychophysiology, 16, 53–55.
Duncan-Johnson, C.C. and Kopell, B. (1981). The Stroop effect: Brain potentials localize the source of interference. Science, 214, 938–940.
Fitzgerald, P.B. and Picton, T.W. (1983). Event-related potentials recorded during the discrimination of improbable stimuli. Biological Psychology, 17, 241–276.
Ford, J.M., Duncan-Johnson, C.C., Pfefferbaum, A. and Kopell, B. (1982). Expectancy for events in old age: Stimulus sequence effects on P300 and reaction time. Journal of Gerontology, 37, 696–704.
Ford, J.M., Hink, R.F., Hopkins, W.F., Roth, W.T., Pfefferbaum, A. and Kopell, B.S. (1979). Age effects on event-related potentials in a selective attention task. Journal of Gerontology, 34, 388–395.
Ford, J.M., Roth, W.T. and Kopell, B. (1976). Auditory evoked potentials to unpredictable shifts in pitch. Psychophysiology, 13, 32–39.
Goodin, D.S., Squires, K.C. Henderson, B. and Starr, A. (1978). Age-related variations in evoked potentials to auditory stimuli in normal human subject. Electroencephalography and Clinical Neurophysiology, 44, 447–458.
Goodin, D.S., Squires, K.C. and Starr, A. (1978). Long-latency event-related components of the auditory evoked potential in dementia. Brain, 101, 635–648.
Goodin, D.S., Squires, K.C. and Starr, A. (1983). Variations in early and late event-related components of the auditory evoked potential with task difficulty. Electroencephalography and Clinical Neurophysiology, 55, 680–686.
Halgren, E., Squires, N., Wilson, C., Rohrbaugh, J., Bab, T. and Crandall, P. (1980). Endogenous potentials generated in the human hippocampal formation and amygdala by infrequent events. Science, 210, 803–805.
Hansch, E.C., Syndulko, K., Cohen, S.N., Goldberg, Z.I., Potvin, A.R. and Tourtellotte, W.W. (1982). Cognition in Parkinson's disease: An event-related potential perspective. Annals of Neurology, 11, 599–607.
Howard, L. and Polich, J. (1985). P300 latency and memory span development. Developmental Psychology, 21, 283–289.
Kutas, M., McCarthy, G. and Donchin, E. (1977). Augmenting mental chronometry. Science, 197, 792–795.
Litzelman, D.K., Thompson, L.W., Michalewski, H.J., Patterson, J.V. and Bowman, T.E. (1980). Visual event-related potentials and depression in the elderly. Neurobiology of Aging, 1, 111–118.
Magliero, A., Bashore, T.R., Coles, M.G.H. and Donchin, E. (1984). On the dependence of P300 latency on stimulus evaluation processes. Psychophysiology, 21, 171–186.
McCarthy, G. and Donchin, E. (1976). The effects of temporal and event uncertainty in determining the waveforms of the auditory event-related potential (ERP). Psychophysiology, 13, 581–590.
McCarthy, G. and Donchin, E. (1981). A metric for thought: A comparison of P300 latency and reaction time. Science 211, 77–80.
Okada, Y.C., Kaufman, L. and Williamson, S.J. (1983). The hippocampal formation as a source of the slow endogenous potentials. Electroencephalography and Clinical Neurophysiology, 55, 417–26.

Pfefferbaum, A., Ford, J.M., Wenegrat, B.G., Roth, W.T. and Kopell, B.S. (1984). Clinical applications of P3: I. Normal aging, II. Dementia, depression, and Schizophrenia. Evoked Potentials, 1, 1–30, 31–50.

Pfefferbaum, A., Ford, J., Roth, W. and Kopell, B. (1980). Age-related changes in auditory event-related potentials. Electroencephalography and Clinical Neurophysiology, 49, 266–276.

Picton, T.W., Stuss, D.T., Champagne, S.C. and Nelson, R.F. (1984). The effect of age on human event-related potentials. Psychophysiology, 21, 312–326.

Polich, J., Ehlers, C.L., Otis, S., Mandell, A.J. and Bloom, F.E. P300 latency reflects the degree of cognitive decline in demending illness. Electroencephalography and Clinical Neurophysiology, in press.

Polich, J., Howard, L.A. and Starr, A. (1985). Effects of aging on the P300 component of the event-related potential from auditory stimuli: Peak definition, variation and measurement. Journal of Gerontology, in press.

Polich, J., Howard, L.A. and Starr, A. (1983). P300 latency correlates with digit span. Psychophysiology, 20, 665–669.

Polich, J., McCarthy, G., Wang, W. and Donchin, E. (1983). When words collide: Interactions of orthographic and phonological factors during word processing. Biological Psychology, 16, 155–180.

Polich, J. and Starr, A. (1983). Middle-, late- and long-latency auditory evoked potentials. In: Moore, E.J. (Ed.). Bases of Auditory Brain-Stem Evoked Responses. Grune and Stratton, Inc: New York.

Pritchard, W.S. (1981). Psychophysiology of P300. Psychological Bulletin, 89, 506–540.

Roth, W.T. (1973). Auditory evoked responses to unpredictable stimuli. Psychophysiology, 10, 125–138.

Shucard, J., Shucard, D. and Cummings, K. (1981). Auditory evoked potentials and sex-related differences in brain development. Brain and Language, 13, 91–102.

Smith, D.B.D., Michalewski, H.J., Brent, G.A. and Thompson, L.W. (1980). Auditory averaged evoked potentials and aging: Factors of stimulus, task and topography. Biological Psychology, 11, 135–151.

Snyder, E. and Hillyard, S.A. (1976). Long-latency evoked potentials to irrelevant, deviant stimuli. Behavioral Biology, 16, 319–331.

Squires, K.C., Chippendale, T.J., Wrege, K.S., Goodin, D.S. and Starr, A. (1980). Electrophysiological assessment of mental function in aging and dementia. In: Poon, L.W. (Ed.). Aging in the 1980's: Selected Contemporary Issues in the Psychology of Aging. American Psychological Association, Washington, D.C.

Squires, K.C., Donchin, E., Herning, R.I. and McCarthy, G. (1977). On the influences of task relevance and stimulus probability on event-related-potential components. Electroencephalography and Clinical Neurophysiology, 42, 1–14.

Squires, K.C., Goodin, D. and Starr, A. (1979). Event-related potentials in development, aging and dementia. In: Lehmann, D. and Callaway, E. (Eds.). Human evoked potentials: Applications and Problems. Plenum Press: New York.

Squires, K.C., Wickens, C., Squires, N.K. and Donchin, E. (1976). The effect of stimulus sequence on the waveform of the cortical event-related potential. Science, 193, 1142–1146.

Squires, N.K., Donchin, E., Squires, K. and Grossberg, S. (1977). Bisensory stimulation: Inferring decision-related processes from the P300 component. Journal of Experimental Psychology: Human Perception and Performance, 3, 299–315.

Squires, N.K., Galbraith, G.C. and Aine, C.J. (1979). Event-related potential assessment of sensory and cognitive deficits in the mentally retarded. In: Lehmann, D. and Callaway, E. (Eds.). Human Evoked Potentials: Applications and Problems. Plenum Press: New York.

Squires, N.K., Squires, K.C. and Hillyard, S.A. (1975). Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. Electroencephalography and Clinical Neurophysiology, 38, 387–401.

Stockard, J., Stockard, J. and Sharbrough, F. (1978). Nonpathologic factors influencing brainstem auditory evoked potentials. American Journal of EEG Technology, 18, 177–209.

Syndulko, K., Hansch, E.C., Cohen, S.N., Pearce, J.W., Goldberg, Z., Montan, B., Tourtellotte, W.W. and Potvin, A.R. (1982). Long-latency event-related potentials in normal aging and dementia. In: Courjan, J., Mauguiere, F. and Revol, M. (Eds.). Clinical Applications of Evoked Potentials in Neurology. Raven Press: New York.