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P300 Latency Correlates with Digit Span

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ABSTRACT

P300 latency from a simple auditory discrimination counting task was obtained along with a digit span memory task for a large group of neurologically normal subjects. Moderate significant negative correlations between the peak latency of the P3a and P3b subcomponents and total memory score were found, although no relationship was observed for other waveform component latencies and memory score. The data suggest that the P300 component of the event-related brain potential may index individual variations in memory ability.

DESCRIPTORS: Event-related potentials (ERPs), P300, Digit span, Memory, Age.

The P300 component of the event-related brain potential (ERP) occurs when subjects attend and discriminate stimulus events which differ from one another on some dimension. It is a large (10–20 μV), positive-going potential with a modal latency of about 300 msec when elicited by auditory stimuli and is of maximal amplitude over the midline at central and parietal scalp areas (Donchin, Ritter, & McCallum, 1978; Pritchard, 1981). Although the exact relationship between the P300 recorded at the scalp and the cognitive events underlying its generation is not clear, several lines of evidence imply that this component is associated with processes related to memory capabilities. Depth electrode recordings and magnetic field studies carried out in humans suggest that the P300 component reflects electrical events originating in the medial temporal lobe areas, most likely including the hippocampal and amygdala brain structures (Halgren, Squires, Wilson, Rohrbaugh, Bab, & Crandall, 1980; McCarthy, Wood, Allison, Goff, Williamson, & Spencer, 1982; Okada, Kaufman, & Williamson, 1983). Since these brain sites have been shown to be important for information storage and learning in both human (Drachman & Arbit, 1966; Horel, 1978; Milner, Corkin, & Teuber, 1968; Squire, 1980, 1982) and animal studies (O'Keefe & Nadel, 1978; Zola-Morgan, Squire, & Mishkin, 1982), their relation-

ship to memory processes is strongly implied. In addition, when P300 latency is obtained with simple auditory or visual discrimination paradigms from cognitively-impaired subjects such as individuals with dementia, retardation, and brain-damage, it is substantially longer than latencies from normal control subjects (Brown, Marsh, & LaRue, 1982; Goodin, Squires, & Starr, 1978; Niwa, Ohta, & Yamazaki, 1983; Squires, Chippendale, Wrege, Goodin, & Starr, 1980; Squires, Galbraigh, & Aine, 1979). Since one of the prominent behavioral deficits observed in these populations is a poor memory for recent events, P300 latency may be reflecting their decreased memory function.

When taken together, these findings converge to suggest that the P300 component and memory processes may be related. In order to examine this relationship, P300 latency and a measure of memory capability, digit span, were obtained from normal subjects. If the latency of the P300 component does index variations of memory ability in cognitively normal subjects, then relatively short latencies should be obtained from those subjects who can remember large numbers of digits and vice versa.

Methods

Subjects

A total of 96 neurologically normal subjects aged 5–87 yrs with approximately equal numbers in each decade (see Table 1 in Results section) were obtained. All subjects were volunteers from the university community and were either currently attending school, gainfully employed, or retired.

Recording Procedures

ERPs were elicited by presenting a series of binaural 1000 or 2000 Hz tones at 60 dBHL with 9.9-msec rise/fall and 50-msec plateau times. The tones were pre-

sented in a random sequence with the high tone occurring 20% of the time and the low tone occurring 80% of the time at a rate of 1.1/sec. Subjects were instructed to keep a mental count of the number of high tones. Stimuli were presented until 200 trials free of movement artifact were recorded. This procedure was performed twice so that two independent observations of the P300 could be obtained in order to provide an accurate assessment of individual latencies with repeated measures.

Electroencephalographic activity (EEG) was recorded at the vertex (C_z electrode site in the 10-20 system) referred to linked mastoids with a forehead ground. The filter bandpass was 1-30 Hz (3dB down, 12 dB/octave slope). While the 1 Hz low bandpass was not optimal, the relative latency of the P300 should not be greatly affected even though its amplitude would be reduced compared to longer time constants (Duncan-Johnson & Donchin, 1979). The EEG was digitized at 3 msec/point for 768 msec and averaged on-line by a Nicolet CA-1000 which also controlled the stimulus presentation and artifact rejection. The separate averages for the rare and frequent stimulus tones were plotted on paper. The latencies of the ERP components at the peak or trough of the potential were obtained by moving an adjustable cursor across the waveform display until the desired position was reached and its latency internally computed. The subject's tone count for each trial block was also recorded. Although the EOG was not monitored, trials on which the EEG exceeded ± 45 μV were automatically rejected.

Memory Task

After the ERP data were obtained, memory capacity was assessed with the Digit Span subtest of the Weschler Adult Intelligence Scale. The experimenter read a series of digits at approximately one number/second and asked the subject to repeat the digits exactly as heard. The series ranged from 3-9 digits in length and were presented in increasing order. The experimenter then read another series that ranged from 2-8 digits in length and the subject was required to repeat them in the reverse order. If the subject did not repeat the series exactly or in the correct reverse order, s/he was presented with another set of the same length. Performance was scored as the total number of digits recalled before two successive errors were made. The total memory score was defined as the number of digits recalled in the forward plus reverse recall conditions.

Results

Examples of the ERP data collected from 4 different subjects are presented in Figure 1. The P300 component obtained to the rare tones was observed to consist of two distinct subcomponents for both sets of trial blocks for 88% of the subjects. These are labelled P3a and P3b and agree in morphology and latency with previous observations of these subcomponents (Ford & Hillyard, 1981; Ford, Roth, & Kopell, 1976; Squires, Squires, & Hillyard, 1975; Snyder & Hillyard, 1976; Roth, 1973). Other com-
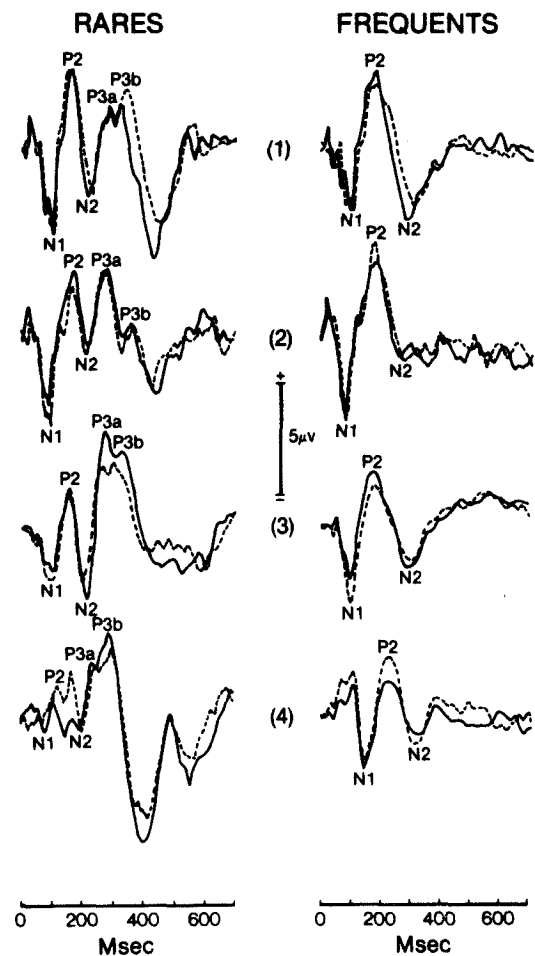

Figure 1. Event-related potentials obtained from 4 different subjects for the rare and frequent stimuli in an auditory count task. The solid trace represents the waveforms obtained to the first trial block while the dashed line represents the waveforms obtained to the second trial block. The primary components are indicated by their associated labels with a positive pen deflection plotted upwards. Note the replicability of the P3a and P3b components within subjects and the variability of peak latencies between subjects (ages: (1) 61 yrs, (2) 72 yrs, (3) 67 yrs, (4) 13 yrs).

ponents for both the "rare" and "frequent" tones are also indicated. For over 95% of the subjects, performance on the counting task was either perfect or within two items of the correct count, with some of the younger subjects making a few more errors.

The mean memory scores for each age group are listed in Table 1. The overall adult mean was quite high at 12.7 digits correctly recalled and was significantly larger ($z = 16.2$, $p < .0001$) than the normative value of 10.2 digits typically observed for this age range (Weschler, 1955).

The scatterplots of the mean component latencies obtained from the 2 trial blocks for the N2, P3a, and P3b and memory scores for each individual are presented in Figure 2 along with their correlation coefficients and regression equations. Little relationship between memory performance and latency of the N2 or other components occurring prior to the P300 portion of the waveform was found (correlations between N1 and P2 component laten-

Table 1

Mean age and size of subject groups by decade, means and standard errors of the primary component latencies, and the mean memory scores for each subject group

| Subject Groups by Age Range	Mean Age	N	Means (SEs in Parentheses)			
			N2 Latency	P3a Latency	P3b Latency	Memory Score
0–9	7.4	9	220 (10.2)	311 (7.3)	385 (12.8)	8.5 (0.7)
10–19	12.2	17	233 (6.0)	286 (9.2)	356 (10.7)	12.3 (0.7)
20–29	23.8	13	208 (7.1)	253 (4.8)	319 (5.8)	13.2 (0.6)
30–39	34.2	13	220 (8.0)	248 (4.0)	315 (5.7)	13.6 (0.8)
40–49	43.3	10	236 (9.5)	275 (7.1)	327 (10.4)	12.4 (0.7)
50–59	54.0	12	233 (7.6)	292 (13.2)	362 (12.3)	12.1 (0.8)
60–69	64.0	16	234 (5.6)	289 (6.2)	355 (6.8)	13.3 (0.6)
70–90	81.0	6	259 (13.9)	325 (13.1)	402 (16.4)	11.8 (1.0)
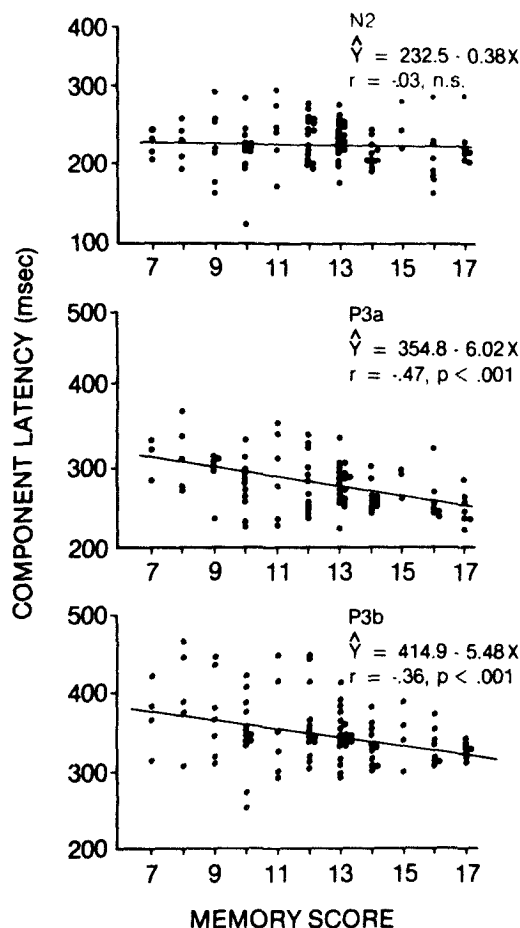
Figure 2. Scatterplots and regression analyses of component latencies and memory scores obtained from the Digit Span subtest of the WAIS for the N2, P3a, and P3b potentials. Clusters of points at a specific score represent different subjects who obtained that score with similar latencies for their components. Each point represents the mean latency of 2 trial blocks.

cies and memory score were −.03 and .11 respectively). In contrast, significant negative correlations between the mean P3a (range: 220–320 msec) and P3b (range: 300–450 msec) latencies and individual memory scores were obtained ($r = -.47$, $t(83) = 4.79$, $p < .001$, and $r = -.36$, $t(94) = 3.69$, $p < .001$, respectively), indicating that shorter P300 latencies are associated with larger memory scores. The correlation between memory score and P3a latency was significantly larger than that obtained for

P3b latency ($t(82) = 1.84$, $p < .05$). Similar correlations were obtained with the forward and reverse digit span scores for P3a ($r = -.42, r = -.43$) and P3b ($r = -.37, r = -.28$) latencies. The association between component latency and total memory score was also observed for both the first and second trial blocks for the P3a ($r = -.42, r = -.46$) and P3b ($r = -.37, r = -.32$) subcomponents.

Because P300 latency has been found to change with age (Brown, Marsh, & LaRue, 1983; Goodin, Squires, Henderson, & Starr, 1978; Pfefferbaum, Ford, Roth, & Kopell, 1980; Polich & Starr, in press), the association between component latency and age was statistically removed by computing partial correlations to control for the effect of age on latency. The resulting correlations were −.09, −.52, and −.40 for the N2, P3a, and P3b mean component latencies and memory scores respectively. The negative correlation between latency of the P300 subcomponents and digit span performance was accentuated when the variability of P300 latency due to age was removed or 'suppressed' with partial correlations (Cohen & Cohen, 1975; Pedhazur, 1982). Thus, P300 latency and memory score covary irrespective of any relationship between subject age and component latency.

Discussion

These data support the suggestion that the latency of the P300 is related to memory capacity in normal subjects. Previous reports comparing P300 latency and digit span performance have found a positive correlation (Brown, Marsh, & LaRue, 1982) and a weak negative correlation (Hansch, Syndulko, Cohen, Goldberg, Potvin, & Tourtellotte, 1982). However, both of these studies employed relatively small samples (15 and 20) and only elderly subjects (50–80 yrs). The restriction of range inherent in correlational data obtained from small samples and the more variable P300 latencies obtained from older subjects (Brown et al., 1983; Ford, Duncan-Johnson, Pfefferbaum, & Kopell, 1982; Polich, Howard, & Starr, Note 1) most likely account for these results. When the correlations obtained in the present study from a large sample and wide range of ages are considered with the finding that abnormally delayed P300 latencies occur in many cognitively-impaired subjects (Goodin et al., 1978; Niwa et al., 1983; Squires et al., 1980; Squires et al., 1979), it is reasonable to assume that the delayed latencies may reflect the influence of a memory-related deficit.

Given these findings, it should also be noted that short-term storage of information is a fundamental attribute of many cognitive activities. For example,

covariations of P300 latency with mental status between and within various subject populations could be indicating differences in cognitive abilities other than or in addition to memory capability (e.g., Brown et al., 1982; Hansch et al., 1982; Squires et al., 1980). However, the combined implications of human depth electrode recordings, animal studies, as well as clinical observations suggest that P300 may be initiated in brain sites related to memory operations. The correlation between P300 latency and digit span performance in normal subjects reported here is consonant with this hypothesis.

The question remains as to why P300 latency should be delayed in an individual whose cognitive apparatus is impaired or why it should vary systematically with a normal individual's ability to maintain digits in immediate memory. These findings may relate to the interpretation of P300 as reflecting a 'context' updating of the stimulus environment (Donchin, 1981; Donchin et al., 1978) in which P300 amplitude changes with both the objective or global probability and the 'subjective' or perceived improbability of the critical stimuli (Duncan-Johnson & Donchin, 1977; Squires, Petuchowski, Wickens, & Donchin, 1977; Squires, Wickens, Squires, & Donchin, 1976; Tueting, Sutton, & Zubin, 1971). These amplitude changes are thought to occur because a new stimulus event is compared to the memory record of previous stimulus events. Relatively infrequent events produce larger amplitude P300s compared to more frequent events because they require a greater change in the memory-maintained context (Donchin, 1981; Donchin et al., 1978). Furthermore, since the P300 is observed when such a memory comparison process occurs, the latency of the waveform peak has been used to measure the timing of categorization and decision processes. Because P300 latency is longer for difficult compared to relatively easy tasks (e.g.,

Kutas, McCarthy, & Donchin, 1977; McCarthy & Donchin, 1981; Polich, McCarthy, Wang, & Donchin, 1983; Ritter, Simson, & Vaughan, 1972; Squires, Donchin, Squires, & Grossberg, 1977), it appears to index the mental chronometry of stimulus discriminations.

If these interpretations are accurate, P300 latency reflects an individual's capacity to retain recently encoded information for comparison with the new, incoming information. If an individual's capacity to maintain a mental representation is diminished due to brain disease or degraded experimentally, the accessibility of previously stored information would be retarded thereby causing slower internal context changes and prolonged P300 latencies. Thus, normal variations in memory capacity would covary with P300 latency as the results from the present study suggest.

That the correlations between memory score and latencies were only observed for the P3a and P3b components and not for any other ERP component indicates that this relationship is specific to those processes underlying the P300. The significantly larger correlation obtained between the latency of the P3a compared to the P3b and total memory score implies that this aspect of the P300 may be more closely tied to those operations of memory related to P300 generation. Interpretations of the P3a as a stimulus "mismatch" detector (Ford & Hillyard, 1981; Snyder & Hillyard, 1976; Squires et al., 1975) support the idea that an enhanced capacity for retaining information about the environment might be reflected by a relatively rapid internal reaction to the detection of changes in that environment. While the strength of this relationship yielded only moderate correlations between latencies and memory capability in the present study, the generally high memory scores obtained may have restricted the possible range of the effect.

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