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Brain potentials in a memory-scanning task. III. Potentials to the items being memorized¹

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Summary Cerebral potentials evoked by items presented for memorization in a memory-scanning task were recorded from subjects ranging in age from 18 to 86 years old. Subjects were divided into younger (average age = 29 years) and older groups (average age = 66 years). Both verbal (digits) and non-verbal (musical notes) stimuli were used. Digits were presented in the auditory as well as the visual modality, and notes were presented acoustically. Potentials are described in terms of their scalp distribution, latency, and amplitude and are compared between the young and old subjects.

Potentials evoked by the memorized items consisted of a positive (P50–90), negative (N100–150), positive (P185–225) sequence in the first 250 msec following stimulus onset. A sustained potential shift then followed whose amplitude differed with the items being memorized. The shift was positive in the parietal region being largest (5 μ V) with verbal items presented visually and slightly smaller (3 μ V) with non-verbal auditory stimuli (the notes); in contrast, verbal auditory digits were not associated with a detectable sustained parietal potential shift. In the frontal recordings there was a sustained potential shift accompanying all stimulus types, which was more negative in the young subjects. The amplitude of these sustained potential shifts differed as a function of the position of the item in the memorized set.

These results provide electrophysiological evidence of brain activity during memorization that varies with the items being processed as well as differing between young and old subjects.

Key words: Brain potentials; Evoked potentials; Memory-scanning task; Verbal stimuli; Non-verbal stimuli

Several studies have used a short-term memory task modified from the one developed by Sternberg (1966) to examine brain potentials accompanying the matching of a probe stimulus with the items in memory, i.e., memory scanning (Marsh 1975; Gomer et al. 1976; Adam and Collins 1978; Ford et al. 1979; Karrer et al. 1980; Gaillard and Lawson 1984; Starr and Barrett 1987), but none have documented the neural events accompanying the memorization process itself. In a tracking

paradigm containing a short-term memory task, memorization of visually presented letters was associated with a sustained potential shift which was affected by memory load (McCallum et al. 1988). In other types of experiments a late positivity has been identified to occur during the presentation of items that subjects were subsequently asked to recognize. Those items correctly recognized were associated with larger positivities on their initial presentation than were the items not recognized (Neville et al. 1986; Paller et al. 1987). A late positivity can also be seen to items that are remembered even though the subject was engaged in a concurrent task, e.g., the Von Restorff effect (Karis et al. 1984; Fabiani et al. 1985, 1986). A feature common to these latter studies was that memorization was incidental, as opposed to being obligatory as it is in the memory-scanning para-

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digm. In a study on orthographic, phonemic or semantic comparisons of pairs of words presented visually (Sanquist et al. 1980), a slow positive component was larger for those items that were subsequently remembered.

In companion reports (Pratt et al. 1989a, b), we reported on the potentials evoked during the identification of a probe as being or not being a member of a previously memorized set. A long-latency (approximately 400–800 msec) sustained parietal positive component (average amplitude 15 μ V) was identified that was affected by the stimulus modality (auditory/visual), stimulus type (verbal/non-verbal) and subject age, being of larger amplitude when non-verbal stimuli (notes) and verbal visual stimuli (digits 1 through 9) were being remembered compared to verbal auditory stimuli (speech synthesized digits).

The purpose of this study was to analyze the potentials evoked by the items being memorized prior to memory scanning to determine the electrophysiological events accompanying memorization. In particular, we wanted to examine the effects of modality and stimulus type (verbal vs. non-verbal notes) on the memory set and to define how these variables might be influenced by subject age.

Methods

Potentials were recorded both during the performance of a modified memory-scanning task and during the performance of a target-detection task in which targets were rare relative to frequent, non-target stimuli ('odd-ball' paradigm). In the memory-scanning task, the potentials evoked by the items in the memorized set were recorded. These items were digits presented acoustically or visually, and notes presented acoustically. In the target-detection task using two of these notes, the potentials evoked by the non-target notes (middle C) immediately preceding and immediately following the target stimuli (C, one octave above middle C) were recorded for comparison with the potentials evoked by the same notes when being memorized.

The subjects, experimental paradigms and procedures of this study were identical to those described in companion reports (Pratt et al. 1989a, b), except that evoked potentials were acquired over a sweep time of 0.96 sec (dwell time = 3.75 msec) for the memorized-set items.

The single-trial evoked potentials of the memory set items were sorted according to their serial position in the memorized set. For the 3- and 5-item memorized sets, the potentials to the first, middle or last item in the set were averaged. Only single trials that were free of eye movements were included in the subsequent analysis. Since performance was almost error-free (Pratt et al. 1989a, b), we were unable to make separate averages to compare correct and incorrect trials. For each subject, 21 averages were obtained: 1 for the 1-item memorized set, 3 for the 3-item, and 3 for the 5-item memorized sets, totaling 7 averages for each of the 3 stimulus types (auditory digits, visual digits, notes). From the single trials of the 'odd-ball' paradigm, 2 average wave forms were obtained: (1) potentials evoked by non-targets immediately preceding targets, and (2) those evoked by non-targets immediately following targets. The absence of eye movements was a prerequisite for inclusion of a single trial in the average. Analysis included measurements of peak amplitudes and latencies from the frontal (Fz) and parietal (Pz) electrodes in the filtered (zero phase shift, low-pass digital filter with a cut-off at 17 Hz) average wave form. Peaks in the potentials evoked by all stimulus types were identified by the strict rule of maximum positivity in a given record following the P2 component. Latencies were measured from stimulus onset and amplitudes were measured relative to the mean voltage during the prestimulus baseline of 120 msec. In addition, a mean amplitude measure in the latency range between 300 and 800 msec after stimulus onset relative to baseline voltage was determined for each wave form. This latency range was chosen to include potential changes in the frontal and parietal electrodes that followed the initial P1 through N2 components. The measurement range was initially determined from grand average wave forms across subjects and subsequently applied to each subject's wave forms by the computer. The mean amplitude

analysis was to complement the peak amplitude measure.

Statistical treatment of the data

Group averages and standard deviations were calculated for peak latencies and amplitudes of the evoked potentials, as well as for mean amplitude in the 300–800 msec range. The components were identified by polarity (P or N) and order of appearance (1, 2, etc.), since component latencies varied between stimulus types by approximately 50 msec. Analysis of variance procedures for repeated measures were used to evaluate the memorized-set data. Effects of age, stimulus type and set size were analyzed separately for peak amplitude and latency of the late potentials at frontal (Fz) and parietal (Pz) locations (age \times stimulus type \times set size). Set sizes compared 3- and 5-item memorized sets over position since there were at least 3 elements in each of these 2 set sizes. Anterior-posterior differences between frontal (Fz) and parietal (Pz) late sustained positive potentials were evaluated separately for amplitude and latency (age \times electrode \times stimulus type \times set size and position in set). Analysis of variance was also conducted on the mean amplitude measures from the frontal and parietal locations to evaluate the effects of age, electrode, stimulus type as well as set size and position within the set (age \times stimulus type \times electrode \times set size and position in set). The Newman-Keuls procedure was used to make post-hoc comparisons of the means. Probabilities below 0.05 were considered significant.

Results

Component definition

The components evoked by the memorized items for the old (solid line) and young (interrupted line) subjects are shown in the grand averages presented in Fig. 1. They consisted, in the Cz derivation, of an N1 component, evident with auditory potentials to digits and notes; a P2 component, evident to all stimulus types; and N2 component evident with notes and to a lesser degree with visual digits. Table I summarizes the mean amplitudes and latencies for young and old subjects for the different experimental situations. A sustained potential shift, labeled P3, followed which was positive in polarity and most prominent in the parietal region for visual digits and to notes but was not present to auditory digits. This difficulty with auditory digits was addressed by using the mean amplitude measure on all potentials. Intersubject variability of the P3 component is demonstrated in Fig. 2, where the potentials evoked by the first item in the 3-item memorized set of visual digits from each of the subjects in the 2 age groups are superimposed. The polarity, surface distribution, amplitude and latency of the sustained potential varied between age groups, stimulus types and set sizes. These differences are presented as follows.

Effect of stimulus type and scalp distribution

Peak analysis. Analysis of the midline distribution of the peak of the sustained shift indicated

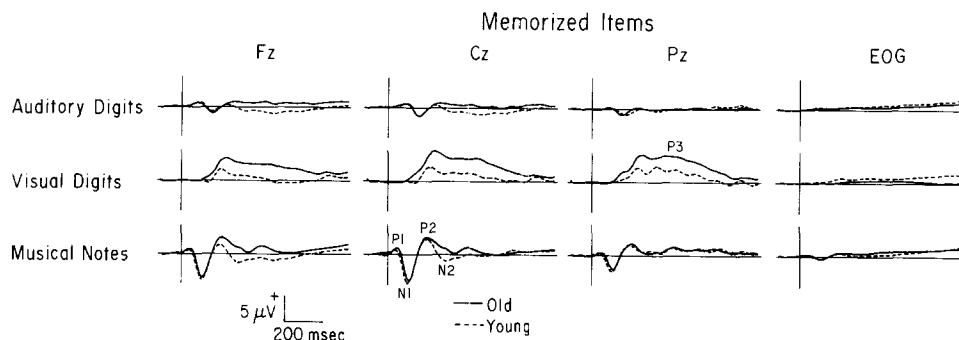


Fig. 1. Superimposed wave forms of the evoked potentials to the memorized-set items from the young and old subjects averaged across set size and position within the set for the 3 stimulus types. Note the sustained frontal negativity and smaller central and parietal sustained positivity in the young subjects during the period labeled 'P3.'

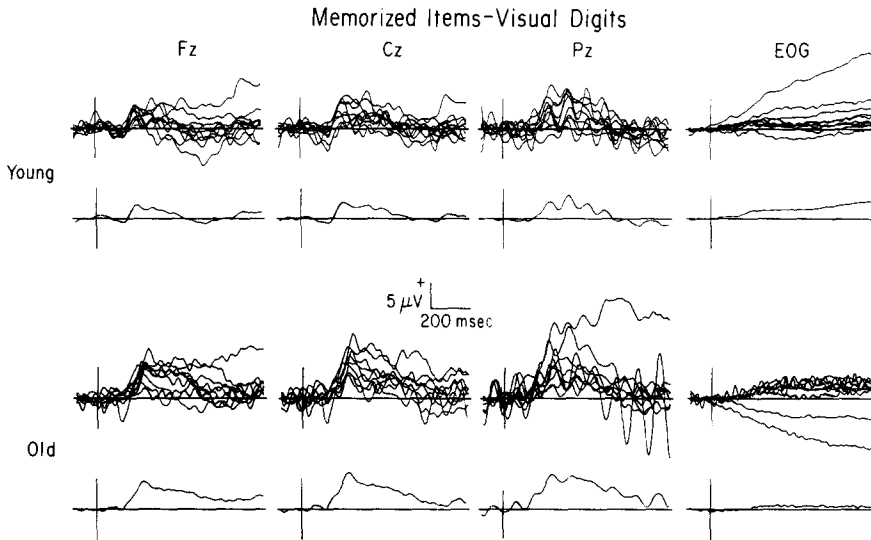


Fig. 2. Superimposed wave forms of the evoked potentials to the first item in the 3-item memorized set to visually presented digits from young and old subject groups. The grand averages of these wave forms are also shown.

smaller amplitudes frontally, and in some instances a negative wave, compared to the parietal records ($P < 0.006$). The means and standard deviations for the peak of the late parietal positivity are given in Table II for stimulus type and set size and position in set. Post-tests indicated that the overall amplitudes of the peak of the parietal positivity to visual digits and notes were not different but that both were significantly larger ($P < 0.001$) than the potentials elicited by auditory digits. Latency measures showed that the sustained potential shift's peak to notes had the shortest latencies, followed by auditory digits and visual digits. Each latency difference between stimulus types was significant ($P < 0.01$).

The peak amplitudes and latencies for the frontal sustained potential shift are shown in Table III. Frontal activity was larger ($P < 0.001$) for visual digits than either auditory digits or notes; amplitude differences between auditory digits and notes were not significant. A significant stimulus type effect ($P = 0.001$) for latencies revealed that notes had shorter latencies than either visual or auditory digits. Latencies for the sustained potential shift at the frontal site for visual and auditory digits were not different.

Mean amplitude analysis. The mean amplitudes for the latency range of 300–800 msec at the frontal and parietal midline electrodes are presented in Table IV. Analysis of the mean amplitude measure indicated a significant stimulus type effect ($P < 0.001$). The overall average amplitude was the smallest for auditory digits, 3 times as large for notes and 8 times as large for visual digits (0.25, 0.77 and 1.96 μV , respectively). Post-tests indicated that the difference between auditory digits and notes was not significant, but the differences between auditory and visual digits, as well as between notes and visual digits, were significant. A significant electrode effect ($P < 0.05$) and electrode \times stimulus type interaction ($P < 0.0005$) were indicated. Parietal mean amplitudes were 6 times as large as their frontal counterparts for the notes and twice as large for the visual digits. For auditory digits parietal mean amplitudes were very small and not different between electrodes.

Effect of set size and position

Peak analysis. A significant electrode \times set size interaction for peak amplitudes was indicated ($P < 0.02$). Frontal amplitudes were not affected

TABLE I

Averages (Ave) and standard deviations (S.D.) for peak latency (lat.) and amplitude (amp.) of the components evoked to the memorized items and to the non-targets in the 'odd-ball' paradigm for young and old subjects at Cz. The components are at the top of their respective column, and the stimulus type is at the left. Latencies are in msec and amplitudes in μV .

| | | | | P1 | N1 | P2 | N2 |
|---------------------|-------|------|------|-------|-------|------|-------|
| Auditory 'odd-ball' | Young | lat. | Ave | 55 | 112 | 202 | |
| | | | S.D. | 7 | 14 | 24 | |
| | | amp. | Ave | 2.51 | -4.65 | 4.23 | |
| | S.D. | | 2.60 | 3.07 | 3.74 | | |
| | Old | lat. | Ave | 57 | 107 | 203 | |
| | | | S.D. | 7 | 6 | 20 | |
| amp. | | Ave | 2.76 | -7.33 | 5.50 | | |
| | S.D. | 1.25 | 3.23 | 2.22 | | | |
| Musical notes | Young | lat. | Ave | 45 | 97 | 185 | 265 |
| | | | S.D. | 10 | 7 | 19 | 29 |
| | | amp. | Ave | 1.63 | -7.09 | 4.56 | -1.49 |
| | S.D. | | 1.08 | 3.12 | 3.09 | 2.34 | |
| | Old | lat. | Ave | 48 | 104 | 193 | 268 |
| | | | S.D. | 12 | 6 | 22 | 41 |
| amp. | | Ave | 2.73 | -6.95 | 4.98 | 0.71 | |
| | S.D. | 1.43 | 2.88 | 2.10 | 2.53 | | |
| Auditory digits | Young | lat. | Ave | 91 | 151 | 225 | |
| | | | S.D. | 14 | 20 | 27 | |
| | | amp. | Ave | 1.48 | -2.58 | 1.44 | |
| | S.D. | | 1.24 | 1.55 | 1.66 | | |
| | Old | lat. | Ave | 94 | 155 | 236 | |
| | | | S.D. | 18 | 19 | 33 | |
| amp. | | Ave | 1.79 | -2.37 | 2.20 | | |
| | S.D. | 1.35 | 1.69 | 1.75 | | | |
| Visual digits | Young | lat. | Ave | 87 | 137 | 209 | 273 |
| | | | S.D. | 33 | 18 | 20 | 25 |
| | | amp. | Ave | 1.46 | -1.08 | 4.25 | 1.07 |
| | S.D. | | 1.68 | 1.54 | 1.95 | 2.28 | |
| | Old | lat. | Ave | 86 | 125 | 216 | 297 |
| | | | S.D. | 43 | 31 | 30 | 53 |
| amp. | | Ave | 2.21 | -0.41 | 7.24 | 3.12 | |
| | S.D. | 2.77 | 1.67 | 3.51 | 3.60 | | |

by set size, whereas late parietal potentials were larger ($P < 0.001$) for the 3-item than the 5-item sets (Table II). No set size effects for latency were found across the scalp. Frontal peak amplitudes were larger for the first items in the sets, while parietal amplitudes were larger for the middle and last items in the 3- and 5-item sets (electrode \times position interaction, $P < 0.001$).

Mean amplitude analysis. The mean amplitude analysis revealed a significant ($P < 0.05$) set size and position within the set effect (mean amplitudes decreasing with increasing set size), with a significant interaction with electrode ($P < 0.0001$).

Parietal mean amplitude measures were more positive than frontal ones for the 1- and 3-item sets. A significant position \times electrode interaction for the mean amplitude measure was indicated ($P < 0.005$). Frontal mean amplitudes were larger for the first items in the sets, while parietal values were larger for the middle and last items in the 3- and 5-item sets.

Effect of age

Peak analysis. Overall, older individuals had larger P3 potentials for all stimulus types than the younger subjects ($P < 0.001$). However, a signifi-

TABLE II

Averages (Ave) and standard deviations (S.D.) for *peak* latency (lat.) and amplitude (amp.) of the late sustained parietal positivity in the young and old subjects. Latencies are in msec and amplitudes in μV . The stimulus evoking the potentials is specified by a 3-character code: A (auditory digits), V (visual digits) or T (notes) representing the stimulus types; 1, 3 or 5 stating the memorized-set size; and a third character providing the position (1; 1, 2 or 3; 1, 3 or 5) of the item within the memorized set.

| | | | Auditory digits | | | | | | |
|-------|------|------|-----------------|------|------|------|-------|------|------|
| | | | A11 | A31 | A32 | A33 | A51 | A53 | A55 |
| Young | lat. | Ave | 480 | 459 | 439 | 450 | 429 | 474 | 486 |
| | | S.D. | 58 | 62 | 67 | 49 | 47 | 56 | 65 |
| | amp. | Ave | 1.93 | 1.29 | 1.90 | 2.86 | 0.26 | 0.77 | 0.90 |
| | | S.D. | 1.83 | 1.67 | 1.65 | 1.75 | 1.32 | 1.98 | 1.15 |
| Old | lat. | Ave | 441 | 454 | 444 | 477 | 465 | 500 | 429 |
| | | S.D. | 85 | 87 | 56 | 92 | 75 | 73 | 71 |
| | amp. | Ave | 1.75 | 1.24 | 2.24 | 0.87 | -0.80 | 1.91 | 3.19 |
| | | S.D. | 2.27 | 2.31 | 1.37 | 3.89 | 3.14 | 1.89 | 2.19 |
| | | | Visual digits | | | | | | |
| | | | V11 | V31 | V32 | V33 | V51 | V53 | V55 |
| Young | lat. | Ave | 504 | 513 | 496 | 493 | 477 | 487 | 478 |
| | | S.D. | 31 | 58 | 76 | 62 | 66 | 65 | 52 |
| | amp. | Ave | 3.18 | 2.78 | 4.04 | 4.18 | 3.31 | 2.64 | 2.68 |
| | | S.D. | 1.65 | 2.45 | 2.25 | 1.55 | 3.22 | 1.27 | 1.97 |
| Old | lat. | Ave | 534 | 514 | 521 | 555 | 527 | 479 | 540 |
| | | S.D. | 97 | 61 | 84 | 49 | 84 | 107 | 61 |
| | amp. | Ave | 5.52 | 6.45 | 4.68 | 6.30 | 4.62 | 5.64 | 5.55 |
| | | S.D. | 5.40 | 5.62 | 4.06 | 5.08 | 6.56 | 3.35 | 4.12 |
| | | | Musical notes | | | | | | |
| | | | T11 | T31 | T32 | T33 | T51 | T53 | T55 |
| Young | lat. | Ave | 433 | 430 | 439 | 429 | 426 | 414 | 418 |
| | | S.D. | 41 | 81 | 48 | 58 | 28 | 55 | 34 |
| | amp. | Ave | 4.06 | 2.10 | 3.60 | 5.75 | 1.80 | 2.45 | 2.62 |
| | | S.D. | 4.02 | 2.75 | 2.96 | 1.96 | 2.05 | 2.28 | 2.70 |
| Old | lat. | Ave | 409 | 452 | 437 | 413 | 397 | 424 | 421 |
| | | S.D. | 72 | 33 | 44 | 51 | 35 | 33 | 83 |
| | amp. | Ave | 4.32 | 3.29 | 3.20 | 5.13 | 2.07 | 2.78 | 3.50 |
| | | S.D. | 1.82 | 3.16 | 1.79 | 2.87 | 2.10 | 2.72 | 1.67 |

cant age \times electrode interaction ($P < 0.05$) indicated that age differences were restricted to the frontal and not the parietal site. None of the peak latency differences between age groups attained significant levels.

A significant ($P < 0.001$) peak amplitude difference in the frontal derivation between young and old subjects to all stimulus types (Table III) was found. The young subjects invariably showed a negative bias relative to the old subjects in the time domain of this sustained potential shift. A significant ($P < 0.02$) age \times stimulus type interaction for the latencies of the frontal P3 indicated

that older subjects had longer latencies for visual digits than younger subjects (see Table III). Latency differences between age groups for auditory digits or notes were not significant.

Mean amplitude analysis. A significant age group effect ($P < 0.02$) revealed that mean amplitudes were more positive in the older subjects over all stimulus types. The overall average mean amplitude for the young subjects was only $0.4 \mu\text{V}$, compared to $1.6 \mu\text{V}$ for the old.

Non-targets in the 'odd-ball' task

In contrast to the potentials evoked by the

TABLE III

Averages (Ave) and standard deviations (S.D.) for *peak* latency (lat.) and amplitude (amp.) of the late frontal sustained-potential in the young and old subjects. Latencies are in msec and amplitudes in μV . The stimulus evoking the potentials is specified by a 3-character code: A (auditory digits), V (visual digits) or T (notes) representing the stimulus types; 1, 3 or 5 stating memorized-set size; and a third character giving the position (1; 1, 2 or 3; 1, 3 or 5) of the item within the memorized set.

| | | Auditory digits | | | | | | | |
|-------|------|-----------------|------|------|-------|-------|------|-------|-------|
| | | A11 | A31 | A32 | A33 | A51 | A53 | A55 | |
| Young | lat. | Ave | 370 | 381 | 318 | 356 | 338 | 355 | 358 |
| | | S.D. | 53 | 43 | 59 | 23 | 50 | 37 | 33 |
| | amp. | Ave | 0.97 | 1.60 | -0.50 | -0.80 | 0.81 | -0.90 | -0.49 |
| | | S.D. | 2.34 | 3.66 | 1.56 | 1.80 | 2.24 | 1.41 | 1.74 |
| Old | lat. | Ave | 362 | 342 | 303 | 348 | 362 | 341 | 336 |
| | | S.D. | 60 | 57 | 53 | 76 | 52 | 40 | 48 |
| | amp. | Ave | 2.56 | 2.13 | 2.21 | 1.38 | 3.22 | 2.40 | 2.16 |
| | | S.D. | 2.17 | 1.85 | 1.50 | 2.03 | 2.75 | 1.76 | 1.64 |
| | | Visual digits | | | | | | | |
| | | V11 | V31 | V32 | V33 | V51 | V53 | V55 | |
| Young | lat. | Ave | 348 | 325 | 325 | 309 | 325 | 321 | 329 |
| | | S.D. | 33 | 41 | 58 | 66 | 61 | 43 | 29 |
| | amp. | Ave | 2.45 | 2.99 | 2.36 | 2.09 | 3.06 | 1.30 | 1.59 |
| | | S.D. | 1.97 | 2.31 | 1.80 | 1.63 | 2.66 | 1.69 | 1.77 |
| Old | lat. | Ave | 391 | 339 | 366 | 385 | 371 | 349 | 383 |
| | | S.D. | 76 | 56 | 70 | 63 | 66 | 61 | 80 |
| | amp. | Ave | 4.44 | 5.12 | 3.63 | 5.81 | 5.68 | 4.06 | 5.39 |
| | | S.D. | 3.88 | 2.48 | 3.01 | 4.39 | 5.55 | 2.41 | 3.31 |
| | | Musical notes | | | | | | | |
| | | T11 | T31 | T32 | T33 | T51 | T53 | T55 | |
| Young | lat. | Ave | 320 | 295 | 306 | 302 | 309 | 322 | 317 |
| | | S.D. | 36 | 46 | 40 | 45 | 32 | 20 | 23 |
| | amp. | Ave | 1.40 | 0.73 | -0.64 | -0.13 | 0.57 | -0.84 | -2.09 |
| | | S.D. | 3.27 | 2.55 | 2.19 | 2.22 | 2.76 | 1.92 | 2.27 |
| Old | lat. | Ave | 305 | 335 | 310 | 298 | 289 | 291 | 306 |
| | | S.D. | 38 | 37 | 33 | 45 | 49 | 38 | 29 |
| | amp. | Ave | 3.58 | 2.86 | 2.53 | 2.41 | 2.88 | 1.42 | 0.77 |
| | | S.D. | 1.93 | 2.17 | 2.35 | 1.41 | 2.67 | 2.08 | 2.11 |

memorized notes in the memory-scanning paradigm, these same notes presented as non-targets in the 'odd-ball' task did not evoke a sustained parietal positivity (Fig. 3, compare potentials at Pz in the time domain indicated by the arrows in the 'memorized items' to the averages above).

Discussion

A long-lasting potential shift was identified that occurred from 300 to 700 msec after the appearance of an item to be memorized. The occur-

rence, amplitude, latency, and midline scalp distribution were affected by both the type and number of items to be remembered and by subject age. These effects were observed using peak amplitude and latency measures, as well as with a mean amplitude measure for the latency range of 300-800 msec.

The sustained potential shift was positive in the parietal region and its occurrence only with certain stimulus types (digits presented visually, and notes) but not others (digits presented acoustically) may seem to suggest its classification as 'exogenous' or stimulus dependent. However, the

TABLE IV

Averages (Ave) and standard deviations (S.D.) for *mean* amplitude measure of the late frontal (Fz) and parietal (Pz) sustained potential in the young and old subjects, in μV . The stimulus evoking the potentials is specified by a 3-character code: A (auditory digits), V (visual digits) or T (notes) representing the stimulus types; 1, 3 or 5 stating memorized-set size; and a third character giving the position (1; 1, 2 or 3; 1, 3 or 5) of the item within the memorized set.

| | | | Auditory digits | | | | | | |
|-------|----|------|-----------------|-------|-------|-------|-------|-------|-------|
| | | | A11 | A31 | A32 | A33 | A51 | A53 | A55 |
| Young | Fz | Ave | 0.11 | 1.09 | -1.18 | -1.62 | 1.01 | -1.32 | -1.36 |
| | | S.D. | 2.67 | 3.78 | 1.61 | 2.20 | 3.24 | 1.50 | 0.80 |
| | Pz | Ave | 0.99 | -0.01 | 0.07 | 1.19 | -0.30 | 0.34 | -0.32 |
| | | S.D. | 1.64 | 1.35 | 1.00 | 1.68 | 1.00 | 1.33 | 1.05 |
| Old | Fz | Ave | 1.33 | 1.04 | 0.55 | 0.16 | 1.92 | 0.57 | 0.80 |
| | | S.D. | 2.68 | 1.93 | 1.57 | 2.68 | 1.83 | 1.76 | 1.94 |
| | Pz | Ave | 0.77 | 0.15 | 1.00 | -0.34 | -1.65 | 1.24 | 0.87 |
| | | S.D. | 2.18 | 1.88 | 0.99 | 2.69 | 3.35 | 1.43 | 1.70 |
| | | | Visual digits | | | | | | |
| | | | V11 | V31 | V32 | V33 | V51 | V53 | V55 |
| Young | Fz | Ave | -0.23 | 0.39 | 0.89 | 0.16 | 1.93 | -0.31 | -0.17 |
| | | S.D. | 1.18 | 2.45 | 2.22 | 1.34 | 3.45 | 1.66 | 1.20 |
| | Pz | Ave | 0.84 | 0.97 | 2.16 | 2.19 | 0.90 | 1.14 | 0.84 |
| | | S.D. | 2.17 | 1.68 | 1.28 | 1.24 | 2.06 | 1.60 | 1.03 |
| Old | Fz | Ave | 2.14 | 2.72 | 1.46 | 2.90 | 3.59 | 3.66 | 1.54 |
| | | S.D. | 3.77 | 2.52 | 2.52 | 3.85 | 5.86 | 3.80 | 2.31 |
| | Pz | Ave | 3.63 | 3.85 | 2.90 | 4.68 | 4.16 | 3.54 | 2.48 |
| | | S.D. | 4.60 | 5.33 | 3.10 | 3.59 | 6.22 | 3.11 | 2.38 |
| | | | Musical notes | | | | | | |
| | | | T11 | T31 | T32 | T33 | T51 | T53 | T55 |
| Young | Fz | Ave | 0.42 | 0.67 | -0.43 | -1.45 | 1.24 | -1.99 | -0.75 |
| | | S.D. | 1.69 | 2.27 | 1.70 | 1.95 | 3.54 | 1.17 | 1.31 |
| | Pz | Ave | 2.12 | 0.05 | 1.55 | 3.37 | -0.07 | 1.09 | 1.01 |
| | | S.D. | 2.33 | 2.02 | 2.21 | 1.09 | 1.65 | 1.26 | 1.38 |
| Old | Fz | Ave | 1.75 | 1.72 | 1.06 | 0.01 | 2.31 | -0.53 | -1.10 |
| | | S.D. | 1.73 | 2.66 | 2.00 | 1.25 | 3.11 | 2.30 | 1.10 |
| | Pz | Ave | 1.64 | 0.74 | 2.15 | 2.91 | -0.04 | 1.40 | 0.70 |
| | | S.D. | 1.34 | 2.19 | 0.97 | 2.00 | 1.42 | 1.58 | 1.37 |

finding using the same notes that this parietal positivity appeared only during memorization in the memory-scanning task, and not during stimulus classification in the 'odd-ball' task, is evidence of its dependence on the requirements of the task and is thus strongly supportive of its cognitive or 'endogenous' origins (Fig. 3). The presence of this sustained parietal positivity during the memorization of only certain items may reflect activity in neural events specific to that type of memorization. The amplitude of this positive shift changed as a function of the position of the item in the memorized set which may also reflect changes in

the processing of the items for memorization. The discrepancy between the occurrence of the positive parietal potential shift with digits presented visually, but not acoustically, is compatible with the hypothesis that verbal stimuli, when presented in the visual modality, need to be recoded before they are available in memory (Sperling 1963; Conrad 1964; Crowder and Morton 1969; Wickelgren 1969; Burrows 1972), whereas verbal material presented in the auditory modality does not require this recoding. The presence of a similar positivity, also peaking at the mid-parietal region, with memorization of notes may indicate that non-verbal

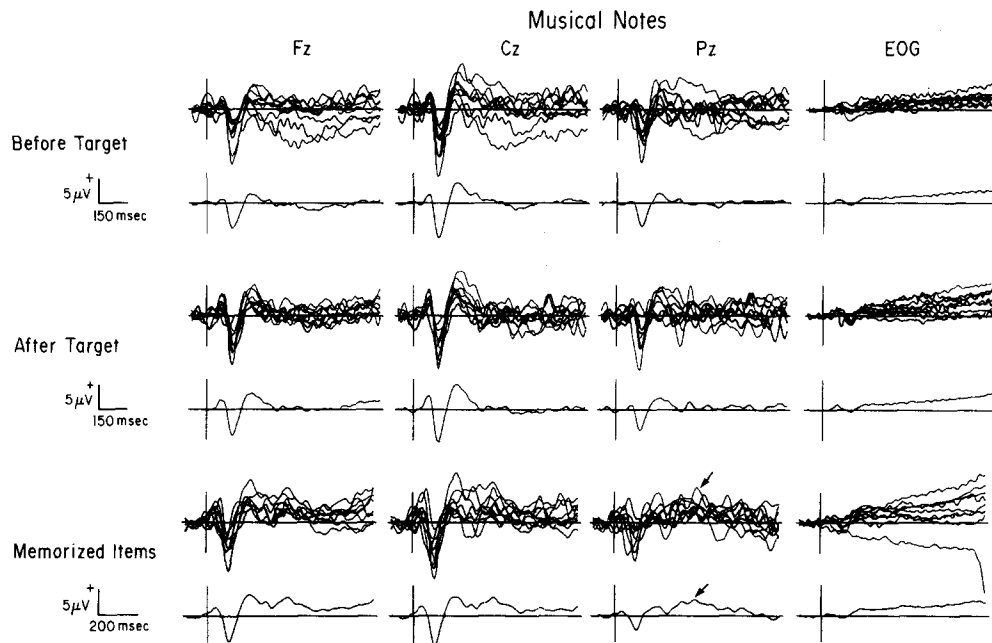


Fig. 3. Superimposed wave forms of the evoked potentials from older subjects in response to non-target musical notes (middle C) immediately preceding and immediately following targets in the odd-ball task, and to the same musical notes when being memorized in the 1-item memorized-set size. Note that although all stimuli were the same musical notes, only those associated with memorization exhibit a sustained parietal positivity (at arrows in PZ). The grand averages of the individual traces are plotted under each superimposed set of records.

material, even when presented acoustically, may also require additional processing steps during memorization.

The parietal positive shift during memorization is of the same latency and duration, but considerably smaller amplitude ($5 \mu\text{V}$ vs. $15 \mu\text{V}$, typically), than the parietal positivity accompanying the processes of memory scanning, i.e., comparing a probe with the items memorized (Pratt et al. 1989a, b). Moreover, during memory scanning a parietal positivity appears with all probes independent of modality or type, whereas during memorization a sustained positivity occurs with only certain stimulus types. Since in the present study a parietal positivity did not accompany memorization of all types of items, it cannot be considered to reflect memorization per se, but rather cognitive processes that accompany memorization. Additional studies are needed to define the relationship of the sustained parietal positivity accompanying the memorization of particular items with the much higher

amplitude sustained parietal positivity accompanying memory scanning.

In incidental memorization studies, evoked potential amplitudes can be compared between those items that are later remembered to those that are not remembered. The nearly perfect performance in this study (Pratt et al. 1989a, b), which is central to the assumptions of the memory-scanning paradigm (Sternberg 1966), did not allow such a comparison.

There was a consistent negative bias in the potentials recorded from the frontal electrode in the young subjects compared to the old subjects during the presentation of the memorized items, independent of stimulus type. The negative bias occurred from approximately 300 to 700 msec after stimulus onset. There are 4 known surface-negative events that could account for the frontal negativity accompanying memorization found in this study: (1) a contingent negative variation (CNV), (2) a premotor negativity, (3) an attention-

related negativity, and (4) processing slow negativity. The possibility that the frontal negativity is generated by neural events underlying the CNV seems unlikely since the succession of items of the memorized set would have been accompanied by the resolution of a CNV, if it were present, about 300 msec after the memorized item was presented. Instead, the sustained frontal negativity only begins at, or about, 300 msec after the appearance of a memorized item and resolves after a further 400 msec, much too soon to be associated with a CNV reflecting expectancy of the next item. The contribution of a premotor negativity is also unlikely because the subjects did not make an overt response to the memorized items. The motor response that was required followed the presentation of the last item by about 2.5–3 sec. The participation of an attention-related N100 type negativity is unlikely, since the frontal negativity accompanying memorization began at too long a latency (300 msec) and persisted for too long (400 msec) to be compatible with the attention-related N100 component. In contrast, the time course and surface distribution of this study's sustained frontal negativity are similar to the selective attention-related 'processing slow negativity' (Nääätänen 1982; Alho et al. 1987).

A frontal sustained processing negativity was reported in a group of 5 young subjects performing a modified memory-scanning paradigm in the visual modality (Kramer et al. 1986). This negativity was detected in the wave forms evoked by the probe stimuli and was found to be sensitive to the degree of probe mismatch with the memorized set, in particular, in a condition which is more likely to develop automatic processing. Assuming a homology of components between our study on memorized items, and the Kramer et al. study on probes, it may suggest that the young subjects in the present study were likely to be utilizing automatic processing, whereas the old subjects may have used controlled processing, which is characterized as slow, serial and capacity limited (Shiffrin and Schneider 1977).

In conclusion, a sustained potential shift was recorded from frontal electrodes (Fz) during memorization of verbal and non-verbal auditory items, as well as visual verbal items, which was signifi-

cantly more negative in young than in old subjects. The differences may reflect neural events accompanying relatively automatic processing by young subjects, and slower, serial processing by the older subjects of items being memorized. The potentials evoked by visual digits and notes also included a sustained late parietal positivity which was absent in response to auditory digits. The sustained parietal shift accompanying the memorization of visual digits and notes but not auditory digits may support the proposition that short-term memory is verbal and auditory in nature and that both non-verbal and non-auditory stimuli require additional processing prior to their memorization. The sustained parietal positive shift accompanying the non-verbal and non-auditory stimuli used in this experiment may reflect such additional stimulus processing.

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