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AGE DIFFERENCES IN P3-REACTION TIME ASSOCIATIONS [1]

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Ford et al. (1979) reported event-related potential (ERP) and reaction time (RT) data recorded during the performance of a memory retrieval task developed by Sternberg (1966). In this task a memory set consisting of serially presented single digits is followed by a probe stimulus, and the subject must decide whether or not the probe was a member of the memory set for that trial. It was found that for both young and old subjects, P3 latency to the probe increased with increasing set size. This finding has been reported by others (Roth et al. 1975, 1977, 1978; Gomer et al. 1976; Marsh 1975) and suggests that P3 latency reflects the greater time required to fulfill the demands of more difficult task conditions. This is consistent with recent research (Kutas et al. 1977; Squires et al. 1977; Duncan-Johnson 1978; Roth et al. 1978) indicating that the generation of P3 is related to the processes associated with stimulus evaluation and that the latency of P3 reflects the relative time taken to evaluate a stimulus sufficiently to perform the task. Two possible relationships between P3 latency and RT could be predicted by this model. To the extent that RT depends on stimulus evaluation time, P3 latency and RT might be associated; to the extent that RT depends on processes other than stimulus evaluation (e.g., response processes), P3 latency and RT would not be associated (Kutas et al. 1977; Squires et al. 1977; Duncan-Johnson 1978).

In Ford et al. (1979) the correlation coefficients between average ERP P3 latencies and average RTs were calculated across subjects for the old subject group and the young subject group. The young subject group had a significant, positive correlation between P3 latency and RT for all 4 set sizes. The old subject group had a significant correlation for set size one only. Here, further analysis of the relationship of P3 latency and RT is pursued using data collected from old and young subjects during a memory retrieval task. A major objective was the investigation of the trial-by-trial relationship of P3 latency and RT and thus the relationship of P3 latency and RT for each individual subject. This was accomplished using an adaptive filter technique (Woody 1967). The current study also partially addresses the often reported finding of smaller amplitude P3s in the average ERP of old as compared to young subjects. This may reflect age-dependent differences in variables known to influence P3 amplitude, such as stimulus probability and attention (Squires et al. 1977). On the other hand, the amplitude differences may depend on latency variability of the individual trial P3s which would be consistent with the observation that elderly subjects are more variable on many measures

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(Botwinick 1975). The adaptive filter provided an assessment of the contribution of latency variability to the observed amplitude difference.

Methods

Subjects

Data from 8 elderly and 12 young women were in the final analysis (4 elderly and 8 young were the same as in Ford et al. (1979)). The elderly subjects ranged in age from 74 to 90 years (mean 83). The young subjects ranged in age from 20 to 29 years (mean 23). In order to minimize confounding degenerative disease and age effects, elderly subjects were selected from a pool of volunteers living in a local retirement community who were in very good health for their age. (Subjects were excluded if they had active symptoms of cardiovascular, renal, respiratory, or endocrine disease.) All subjects attended a screening session during which the study was described, medical history was taken, physical examination was performed, and their informed consent was obtained.

Task

Subjects received a series of trials in a visual memory retrieval task devised by Sternberg (1966). The stimuli were the digits 0 through 9. On each trial a memory set of 1, 2, 3, or 4 digits was presented serially (on for 1 sec with a 1 sec interstimulus interval). One second after the memory set was completed, a 0.5 sec warning tone (60 dB SL, 1000 c/sec) preceded the presentation of the test (probe) stimulus. The subject's task was to press one of two response buttons indicating whether or not the probe was a member of the memory set for that trial, i.e., whether the probe was 'inset' or 'outset'. Direction of press was balanced across subjects. Subjects were instructed to fix their gaze on an illuminated point in the center of the display screen. The presentation of the stimuli (digits) was random with the restriction that each set size, each position of the probe digit in the memory sequence, and inset and outset trials all occurred with equal frequency. There were a total of 192 trials — 24 trials of each type (inset × outset × set size). The trials were presented in three 15 min blocks with 5 min rest periods between blocks; the experiment lasted about 1 h.

Recording

The electroencephalogram (EEG) was recorded from the Fz, Cz and Pz scalp locations referenced to linked ears using Beckman Ag/AgCl disc electrodes. The electro-oculogram (EOG) was recorded from electrodes above and below the right eye to allow detection of records contaminated with electrical artifacts produced by eye blinks and shifts in gaze. The bandpass of the amplifiers was 0.03—100 c/sec (3 dB points of 6 dB/octave rolloff curves); the time constant was 5.3 sec.

Data analysis

The P3 is generally maximal at Pz, and Kutas et al. (1977) have demonstrated that the highest correlation between single trial P3 latency and RT is obtained at Pz. Therefore, the single trial analysis was performed only on the data recorded at Pz using a PDP-12 minicomputer. ERPs to the probe digit were rejected if the EEG saturated the A-D converter (exceeded ±100 μV). Trials in which the reaction time was less than 100 or greater than 2500 msec were rejected. The EEG was sampled every 10 msec and the trials were subjected to a low-pass digital filter which approximates zero phase shift with a high frequency limit of 6.8 Hz (down 3 dB) (Wilcock and Kirsner 1969). Eyeblink artifact was dealt with by rejecting trials in which the EOG excursion exceeded 40 μV. The EOG rejection rate averaged 6.8 (young) and 5.3 (old) trials per category (24 trials); RT rejection rates were 1.4 (young) and 2.2 (old) trials per category.

The single trial adaptive filter analysis proceeded as follows: (1) peak P3 latency of the averaged ERP was determined by identifying

the largest positive point between 280 and 700 msec; (2) a portion of the averaged ERP — the P3 peak ±130 msec — was defined as a template; (3) the 260 msec wide template (P3 peak ±130 msec) was moved at 10 msec increments across each single trial; (4) the 'distance' (time in 10 msec increments) moved by the template in order to produce the highest correlation between the template and the single trial was determined; (5) the single trial P3 latency was calculated by adding this 'distance' to the template P3 latency; (6) a new average was created aligning the single trials on the points of maximum correlation (i.e., aligning each single trial with every other on its P3 latency); (7) the operation then returned to step 1, and determined a new template from this new average; (8) the entire process was repeated for a total of 3 iterations.

The correlation between the reaction time (RT) and the latency of the point of maximum template correlation for each single trial was determined using the first iteration. This produced an estimate of the correlation between the RT and P3 latency (hereinafter referred to as P3-RT correlation) for each subject based on her single trial data for each of the 8 conditions (4 set sizes and 2 response types). These data were z transformed and submitted to an analysis of variance. In addition, P3-RT correlations were computed for each subject individually, collapsing across set size for the inset and outset response types.

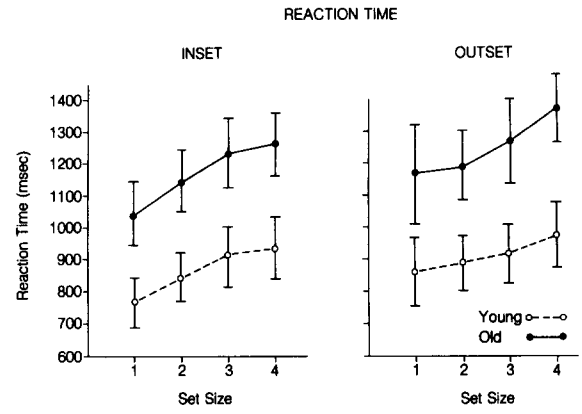

Fig. 1. Mean reaction times for old (solid lines) and young (broken lines) subjects for 4 set sizes for inset and outset response types. Brackets are standard error of the mean in all figures.

Results

Behavioral data

RTs were longer for old than for young subjects ($F(1, 18) = 6.12$, $P < 0.025$). RT increased with set size ($F(3, 54) = 35.14$, $P < 0.001$) (Fig. 1). RT variability was assessed by analysis of the standard deviation of each individual's single trial RTs. It did not vary with age, group, set size, or response type (inset or outset). The number of *hits* (pushing the correct button), *misses* (pushing the wrong button), and *omissions* (pushing no button) were calculated (Table I) and 3-way analyses of variance were done for each mea-

TABLE I

Behavioral data.

	Inset					Outset				
Set size	1	2	3	4	$\bar{X}$	1	2	3	4	$\bar{X}$
Young subjects										
% Hits	97.1	95.5	91.3	94.4	94.6	92.5	94.8	95.1	92.5	93.7
% Misses	0.4	1.0	2.4	1.7	1.4	1.4	1.0	1.7	1.7	1.5
% Omissions	2.5	3.5	6.3	3.8	4.0	6.1	4.2	3.1	5.8	4.8
Old subjects										
% Hits	88.5	94.3	93.2	87.0	90.8	80.1	94.7	95.3	93.0	90.8
% Misses	0.6	0.5	1.6	6.1	2.2	4.0	1.6	1.0	3.5	2.5
% Omissions	10.9	5.2	5.2	6.8	7.0	15.9	3.7	3.6	3.5	6.7

sure. There was a significant age × set size interaction for *hits* ($F(3, 54) = 5.71$, $P < 0.01$) and for *omissions* ($F(3, 54) = 6.84$, $P < 0.001$). Internal analyses revealed that these effects were due to elderly subjects having fewer *hits* ($F(1, 18) = 4.40$, $P < 0.05$) and more *omissions* ($F(1, 18) = 4.48$, $P < 0.05$) than young subjects for set size of 1. There was an age × set size interaction for *misses* ($F(3, 54) = 2.84$, $P < 0.05$); the old subjects had significantly more *misses* than did the young but only for the largest set size ($F(1, 18) = 7.17$, $P < 0.05$).

Amplitude

The amplitude of P3 increased with each iteration of the adaptive filter ($F(1, 18) = 157.6$, $P < 0.001$) (see Fig. 2). The young subjects had significantly larger P3 amplitudes than the old. Although the adaptive filter adjustment for latency variability increased P3 amplitude, the amplitude difference between young and old subjects remained ($F(1, 18) = 10.35$, $P < 0.01$). The adaptive filtering did, however, produce a greater increase in amplitude for the young than for old subjects (group × iteration interaction, $F(3, 54) = 3.56$, $P = 0.02$).

Latency

The single trial estimates of P3 latencies (i.e., the average of the single trials) were greater (longer latency) than the latencies measured from the averaged ERP ($F(3, 54) = 31.62$, $P < 0.001$) (Fig. 2). However, the same relationship demonstrated between the averaged ERP P3 latency and the experimental variables was present for the single trial P3 latencies. Both averaged and single trial P3 latencies to inset probes were significantly shorter than to outset probes for the young subjects ($F(1, 11) = 26.77$, $P < 0.001$; $F(1, 11) = 23.03$, $P < 0.001$), but not for elderly ($F(1, 7) = 1.38$, n.s.; $F(1, 7) = 1.81$, n.s.) (see

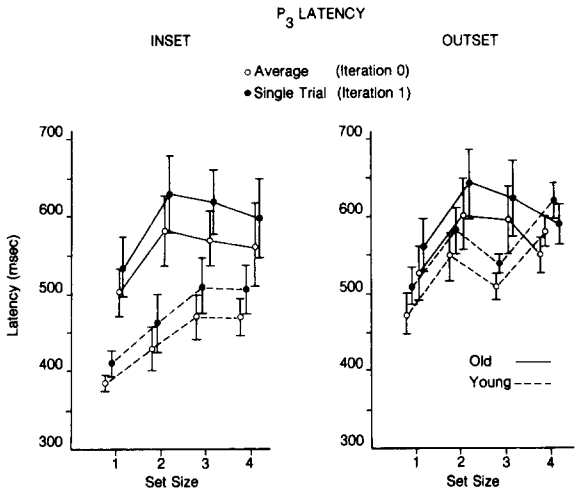

Fig. 2. P3 latency data for old (solid lines) and young (broken lines) subjects for 4 set sizes and 2 response types. The open circles represent the mean P3 latencies of the average ERP. The solid circles represent the mean single trial latencies from the first iteration of the adaptive filter. Note that the mean single trial estimates of P3 latency are later than the latency of the average ERP.

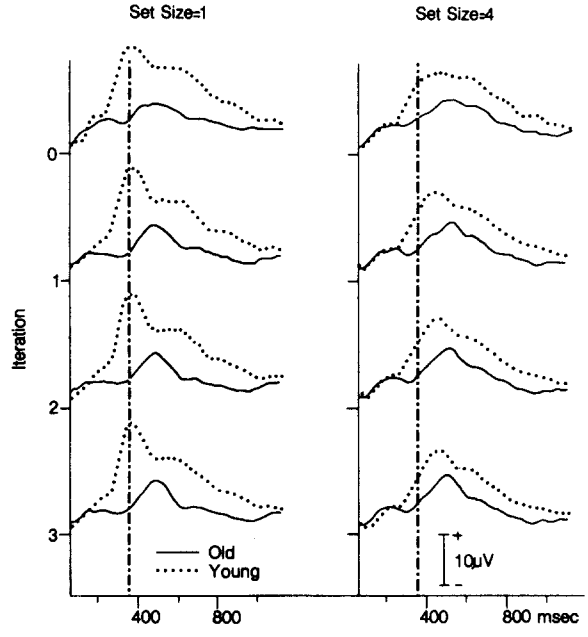

Fig. 3. Grand average ERPs for old (solid line) and young (dotted line) subjects superimposed. The top averages (iteration 0) are before application of the adaptive filter. The bottom 3 tracings are averages constructed after successive applications of the adaptive filter. Set size 1 and 4 for the inset response type are shown. A dashed vertical line is drawn 360 msec after stimulus presentation for a time reference.

Fig. 4). The standard deviation of the latencies of individual P3 peaks provided an estimate of the latency variability or 'jitter' of the single trials; analysis of variance of this measure revealed that it did not vary with age group, set size or response type.

P3-to-response interval

The amount of time elapsing from the P3 peak to the button press (hereinafter referred to as P3-to-response interval) was greater for old than for young subjects ($F(1, 18) = 4.57$, $P < 0.05$). For the elderly this interval increased from 551 msec to 715 msec from set size 1 to 4 ($F(3, 54) = 3.30$, $P < 0.03$). For the young, the amount of change was smaller (352—437 msec) and was not statistically significant. The P3-to-response interval decreased with each iteration of the adaptive filter ($F(3, 54) = 31.69$, $P < 0.001$) as the later occurring single trials were identified. The relationship of the P3-to-response interval to the other variables (age group, response type, set size) was the same for the single trial as for the average ERP measures of P3 latency.

P3-RT correlation

The single trial P3-RT correlation across the 4 set sizes (i.e., correlations for each subject using the single trial P3 latency and RT from all 4 set sizes together in a single calculation) is plotted separately for the inset and outset response types for each subject (Fig. 5). For the inset trials, the correlation was positive for all 12 young subjects and 8 of the 12 reached statistical significance (i.e., had P3-RT correlation which was significant at the 0.05 level). For the old subjects, however, the correlations were positive for only 4 subjects, negative for the other four, and reached statistical significance for only two subjects (one positive and one negative) (Fig. 5). The pattern of results was similar for

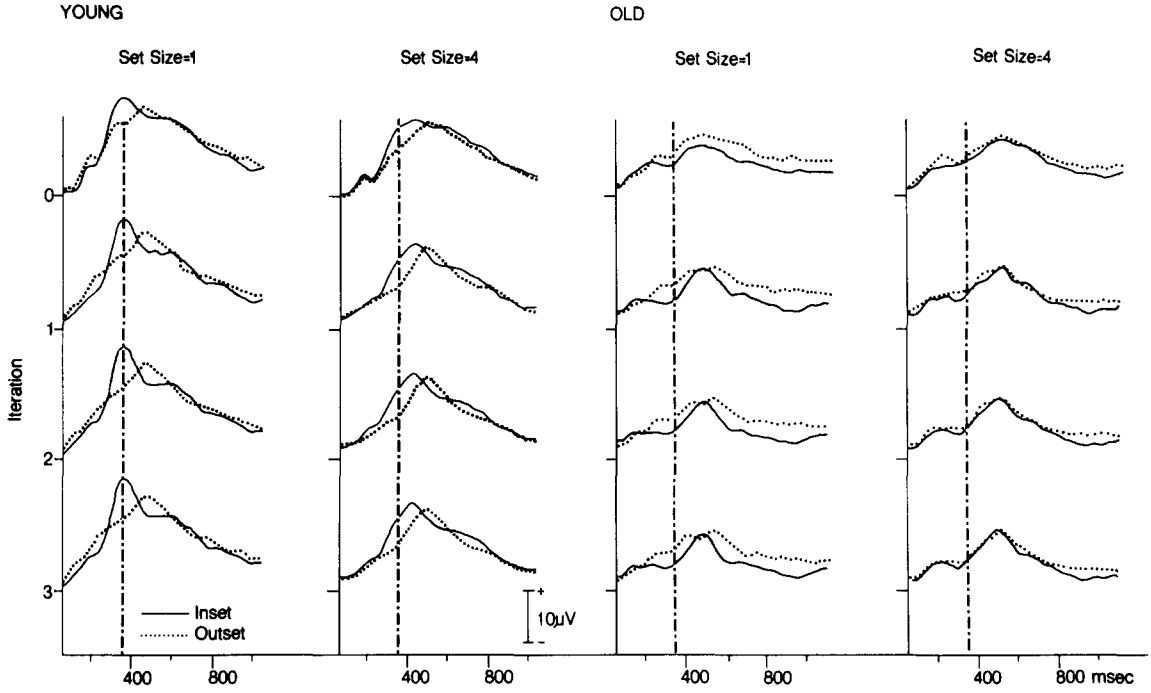

Fig. 4. Grand average ERP with inset (solid line) and outset (dotted line) superimposed for set size 1 and 4. Young subjects are on the left and old on the right. The top tracings are averages before application of the adaptive filter and the bottom 3 tracings are averages constructed after application of the adaptive filter. The dashed vertical line is drawn 360 msec after stimulus presentation.

the outset response types but the correlations were generally smaller (Fig. 5). A 2-way analysis of variance (age group X response type) was performed on the z transformed P3-RT correlations. Young subjects had higher correlations than the old subjects ($F(1, 18) = 9.83$, $P < 0.01$).

A 3-way analysis of variance (age group X response type X set size) was performed on the z transformed P3-RT correlations calculated separately for each subject, for each response type and for each set size. This analysis differs from the previous one in that each subject had 8 different single trial P3-RT correlations, one for each set size for both inset and outset response types. The young subjects had higher P3-RT correlations than the old ones but this did not reach statistical significance (group main effect $F(1, 18) = 3.37$, $P = 0.08$). There was a significant 3-way interaction of group X response type X set size ($F(3, 54) = 2.79$, $P < 0.05$). Subanalyses revealed that set size was a significant factor only for the old subjects for the inset response type ($F(3, 21) = 3.17$, $P < 0.01$). The relationship was not linear (r for set size 1 = 0.26, 2 = −0.08, 3 = 0.14, 4 = −0.06) but the smallest set size did produce the highest correlations.

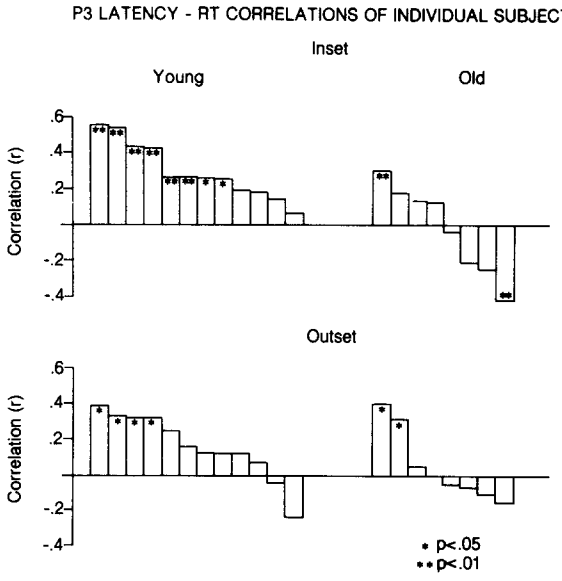

Fig. 5. Single trial P3 latency-RT correlations for each individual subject calculated across the 4 set sizes. The top graph presents the correlations for the inset response types and the bottom graph the outset items. * and ** indicate that the correlations are statistically significant.

Discussion

The old subjects differed significantly from the young in several respects: (1) P3 amplitude at Pz was smaller; (2) P3 and RT were slower; (3) the relationship between P3 latency and RT was considerably altered. The adaptive filter analysis provided information about the contribution of latency variability to the observed amplitude differences and about the relationship between P3 latency and RT within individual subjects. Alterations in this association may reflect age-related changes in cognitive strategies in performing complex tasks.

The amplitude difference between the old and young subjects is quite large. The application of the adaptive filter increased the amplitude of all the data, as would be expected. This increase in amplitude was most prominent after the first iteration with only small increments being added with iterations 2 and 3. The hypothesis that the amplitude difference between the old and young subjects was due to an increase in latency variability in the old was not supported. The amplitude differences persisted after adaptive filtering and the young subjects actually showed a greater increase in amplitude than did the old with latency adjustment.

The mean single trial measurement of P3 latency was generally greater than the latency of the average ERP. This suggests that there were a significant number of single trials with latencies longer than that of the average ERP but which were not of large enough amplitude or of sufficient uniformity in latency to influence the latency of the average ERP.

The latency of P3 (measured both from the average and from the single trials) increased with set size up to set size 3 for the young

and only up to set size 2 for the old subjects. This saturation effect (failure to increase in latency after set size 2 or 3) was not prominent in the data presented by Ford et al. (1979). Several factors may account for this discrepancy: (1) Ford et al. pooled data across 3 electrode sites (Fz, Cz, Pz) because electrode location did not interact with the other variables in an analysis of variance; (2) the subject populations were similar but not identical; (3) in the data presented here, single trials in which there were eye blinks were selectively excluded, whereas Ford et al. excluded *subjects* from the analysis if their average ERPs demonstrated significant eye blink in the EOG lead. The differences in these analysis strategies resulted in different subjects and different trials in the final data base.

Adam and Collins (1978) used a memory search paradigm with a larger range of set sizes (1, 3, 5, 7, 9, 11) and found late positive component latency saturation at a set size of 7. A major difference between their study and the data presented here was the approach to the identification of the late positive components. They concluded that there were at least two components ($\overline{P270}$ and $\overline{P350}$) which merged for the smaller set sizes but separated for the larger set sizes. In the present study, some subjects did have multiple peaks, but these often seemed to be superimposed on a slower, single component. We chose, therefore, to make the assumption that there was only a single P3 component and used the definition of the largest positive point in a latency range to determine the latency of this component. This major difference in the identification of the late positive components could account for the differences between the two studies.

Without single trial analysis one is limited to the calculation of within-group correlations between the latency of the average ERP and the mean RT. With average ERPs a positive correlation indicates that individuals with slow RTs have long P3 latencies and vice versa but says nothing about the correlation of P3 and RT within individuals. The single trial analysis, however, provides information about the relationship of P3 latency and RT within a single subject. The data presented here demonstrate that young subjects have significantly higher single trial P3-RT correlations than the old subjects. In addition the P3-to-response interval was smaller for the young subjects than the old. Thus, it appears that the P3 latency and RT are more tightly coupled in the young.

The P3-to-response interval increased significantly with set size for the elderly but not for the young. Thus, as the memory task becomes more demanding the elderly reveal a greater dissociation between P3 latency and RT. Ford et al. (1979) suggested that the time from P3 to the response (P3-to-response interval) is affected by confidence, being longer when the subject is less confident, as would be the case following a difficult task condition (e.g., set size 4). A lack of confidence in a preliminary stimulus evaluation may result in a slowness to initiate the response, slowness to move, or in a tendency to re-evaluate items in memory. Jordan and Rabbitt (1977) found that as task difficulty was increased, RTs of old subjects slowed more than did the RTs of young subjects. However, with practice this effect disappeared leaving just an age lag constant. This suggests that with enough practice in our task, there would be an age lag constant between P3 and RT instead of an age differential, which is to say that perhaps the factor that dissociates P3 from RT could be practiced away.

It has been repeatedly demonstrated that 'negative' responses (correct answer is 'no') require longer to perform than equivalent 'positive' responses (correct answer is 'yes') (see Nickerson 1972, for a review). Both young and old subjects had longer RTs for the outset than inset items which is consistent with the inset responses being 'positive' and the outset being 'negative'. The young subjects also had longer P3 latencies for the outset than inset items. The old had a similar but much smaller and not statistically significant

inset-outset P3 latency difference. In the young the inset-outset difference in P3 latency suggests that the additional time required for the negative response is incorporated into the 'stimulus evaluation time' (defined as the operation which must be completed before the P3 is generated). This is also supported by the observation that the young subjects did not have longer P3-to-response intervals for the outset as compared to inset items. This elapsed time would be longer for the outset items if the additional time required for a negation operation occurred after stimulus evaluation was completed. In contrast, the old subjects did have longer (although not statistically significant) P3-to-response intervals for the outset items. Perhaps the old subjects complete stimulus evaluation and then perform the negation operation, adding to the elapsed time from P3 to RT; young subjects complete stimulus evaluation and the negation operation simultaneously or before P3. While this is merely speculation which must be tested with further experimental manipulation it suggests that there is a difference between old and young in the sequence and timing of the underlying cognitive operations leading up to a response.

Summary

Eight healthy old and 12 healthy young women had event-related potentials (ERPs) recorded during the performance of a memory retrieval task. For each subject the single trial data recorded at Pz were analyzed using Woody's adaptive filter technique. The old subjects differed from the young in several respects: P3 amplitude at Pz was smaller, P3 latency and reaction time (RT) were greater, the relationship between P3 latency and RT was considerably altered.

The adaptive filter increased the amplitude of P3 but the age-related amplitude difference persisted, suggesting that this difference is not due to increased latency variability with age. The old subjects had lower single trial P3-RT correlations and longer elapsed time from P3 peak to the response than did the young subjects. Both groups had greater RTs for outset items ('negative' responses) than for inset items ('positive' responses). For the young subjects P3 latency was also greater for the outset compared to the inset items but this difference was not found for the old subjects. Thus, the relationship between P3 latency and RT is altered in the aged — P3 and RT are less tightly coupled than in the young.

Résumé

Différence suivant l'âge des associations entre P3 et temps de réactions

Le potentiel lié aux événements (ERP) a été enregistré chez 8 femmes âgées bien portantes et 12 jeunes femmes bien portantes au cours de la réalisation d'une tâche de mémorisation. Chez chaque sujet les données par simple essai enregistrées à Pz ont été analysées à l'aide de la technique de filtre adaptatif de Woody. Les sujets âgés différent des sujets jeunes sur plusieurs points: l'amplitude de P3 à Pz est moindre, la latence de P3 et le temps de réaction (RT) sont plus grands, la relation entre la latence de P3 et RT est considérablement altérée.

Le filtre adaptatif augmente l'amplitude de P3, mais les différences d'amplitude liées à l'âge persistent suggérant que ces différences ne sont pas dues à une augmentation de variabilité de latence avec l'âge. Les sujets âgés ont des corrélations entre P3 par essai simple et RT moindres et un temps entre le pic de P3 et la réponse plus long que les sujets jeunes. Les deux groupes ont des RT plus grands pour les items 'outset' (réponses négatives) que pour les items inset (réponses positives). Chez les sujets jeunes la latence de P3 est également plus grande pour les items outset que pour les items inset mais cette différence n'a pas été retrouvée chez les sujets âgés. Ainsi, la relation entre la latence de P3 et RT est altérée chez les sujets âgés, P3 et RT étant moins étroitement couplés que chez les sujets jeunes.

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