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ERP repetition effects in indirect and direct tasks: Effects of age and interitem lag

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Abstract

Event-related potentials (ERPs) were recorded for visually presented words in young and older participants while they performed two tasks. In the indirect task, participants responded to occasional target words. Some of the nontarget words were repeated after a single intervening trial, and others were repeated after a mean of 10 trials. In the direct task participants responded to every item, discriminating between words presented for the first and the second times. Compared with ERPs to unrepeated words, those to words repeated in the indirect task after either lag were more positive in both participant groups. For the short lag, this effect was larger among the older participants. In the direct task, words repeated after either lag elicited a positive shift in the ERPs of the young participants. In the older participants, short lag repeats elicited a repetition effect, but smaller than the equivalent effect among the young participants. Long lag repeats failed to elicit a repetition effect in the direct task in the older participants. The findings show that word repetition in these tasks reflects the modulation of two ERP components, which differ in their sensitivity to age-related changes in memory function.

Descriptors: Aging, Late positive component, N400, Repetition effect, Recognition memory

In numerous studies, event-related brain potentials (ERPs) have been employed to investigate differences in the brain activity elicited by repeated and unrepeated stimuli, with the goal of gaining insight into the neural and cognitive bases of memory (for a review, see Rugg, 1995). A large number of these studies have investigated the effects on ERPs of word repetition over relatively short intervals of time within a single, uninterrupted stimulus sequence. Several studies have compared ERPs evoked by "old" and "new" words in the continuous recognition memory task, in which memory is tested directly by requiring participants to discriminate between words presented for the first or the second time (e.g., Friedman, 1990; Rugg & Nagy, 1989; Rugg, Roberts, Potter, Pickles, & Nagy, 1991). In a larger number of studies, the repetition of the critical items was incidental to the task, the difference between ERPs evoked by first and second presentations serving as an indirect index of memory (e.g., Nagy & Rugg, 1989; Rugg, 1987; Rugg, Furda, & Lorist, 1988).

A finding common to both types of task is that ERPs evoked by old (i.e., repeated) items are more positive than those evoked by new items. In healthy young participants, this positive shift onsets at approximately 250 ms and continues for about another 300 ms. In direct memory tasks, the shift is often referred to as the *old/new effect*; in the context of indirect memory tasks, the shift is usually called the *ERP repetition effect*. These different terms serve as a reminder that there is no reason a priori to assume that the two effects are either neurally or functionally equivalent and that the methods used to elicit them differ in at least one important respect: Whereas the ERPs to old and new words in direct tasks are formed from items correctly judged as such, the critical ERPs in indirect tasks are, of necessity, formed without reference to participants' perceptions of whether the items are old or new. For the sake of simplicity, however, the effects obtained in each type of task will be referred to as ERP repetition effects.

Current evidence suggests that in both indirect and direct tasks, ERP repetition effects can reflect the modulation of at least two temporally and spatially overlapping components (for a review, see Rugg & Doyle, 1994). The earlier of these components is negative going and is attenuated in ERPs evoked by repeated items. This component is generally held to be the N400, originally identified by virtue of its sensitivity to semantic and contextual priming manipulations (Kutas & Hillyard, 1980). The second component is positive going and is enhanced in ERPs to repeated items. This late positive component might be allied to the well-studied P300. The N400 and late positive component have been dissociated in indirect tasks as a function of word frequency (Rugg, 1990; Young & Rugg, 1992) and according to whether repetition is within or across

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sensory modality (Rugg, Doyle, & Wells, 1995). In direct tasks, the two components have been dissociated on topographical criteria, the late positive component having the more posterior distribution, and as a function of the interval over which repetition occurs (Rugg & Nagy, 1989). Rugg and Nagy reported that both components were modulated in a continuous recognition task when up to 19 items intervened between successive presentations and that a delay of 45 min was sufficient to abolish the modulation of the N400 but not the late positive component.

The fact that ERP repetition effects can be elicited by repetition over interitem lags that exceed short-term memory capacity (i.e., more than seven or eight items) indicates that the effects are independent from short-term memory. Beyond this, the functional significance of the effects is unclear. Although N400 modulation has been found in indirect memory tests—the kind of tests often used to study repetition priming and other behavioral manifestations of implicit memory (Richardson-Klavehn & Bjork, 1988)—N400 modulation most likely does not directly reflect processes underlying long-term implicit memory, as the longevities of the ERP (<15 min; Rugg, 1990) and behavioral (hours or days) effects are not comparable. However, it is equally unlikely that N400 modulation reflects processes necessary for the explicit recognition of repeated items. Modulation of the N400 was not found when words were presented in a recognition memory test approximately 45 min after first being presented, although memory for the words was well above chance (Rugg & Nagy, 1989).

Arguably, more progress has been made in uncovering the functional significance of that part of the repetition effect attributable to the modulation of the late positive component. The results of several studies of recognition memory, all employing study–test intervals of several minutes or more, converge to suggest that enhancement of a parietal-maximum late positive component is a sign that the eliciting item has been recognized as old on the basis of the retrieval of a prior study episode involving the item (recollection) (Paller & Kutas, 1992; Rugg, Schloerscheidt, Doyle, Cox, & Patching, 1996; Smith, 1993; Wilding, Doyle, & Rugg, 1995). If these results can be generalized to tasks with much shorter intervals between successive presentations, then the late component of the ERP repetition effect can be linked to processes implicated in recollecting the first occurrence of the eliciting item. An obstacle to making this generalization, however, is that the scalp distribution of the enhanced late positive component elicited by old words in experiments employing the study–test procedure differs from that typically found for the continuous recognition task; whereas the scalp distribution associated with the study–test procedure is larger over the left hemisphere (Rugg, 1995; Rugg et al., 1996), the distribution associated with the late positive component in continuous recognition appears to be symmetrical. Evidently, therefore, the two effects do not share entirely the same populations of neural generators, and the degree of overlap between the generators is uncertain.

In summary, evidence from studies of young healthy individuals suggests that the ERP repetition effects found when items are repeated over short intervals reflect modulation of the same two ERP components, irrespective of whether repetition is in the context of an indirect or a direct task. This is not to say, however, that the relative contributions of the two components are equivalent in the two types of task or even in different versions of the same task. The functional significance of the modulation of the earlier component, the N400, is unclear, but is unlikely to reflect processes necessary for explicit memory. By contrast, the later-occurring enhancement of the late positive component may reflect processes that either underlie, or are contingent upon, recollection of the evoking item.

A number of studies have recently compared ERP repetition effects in indirect tasks in young and older participants (for a review, see Friedman, 1995). In some of these studies (Friedman, Hamberger, & Ritter, 1993; Friedman, Hamberger, Stern, & Marder, 1992; Rugg, Pearl, Walker, Roberts, & Holdstock, 1994), the task was to detect target items (nonwords or words from a designated semantic category) while witholding responses to nontarget words, a proportion of which were repetitions of previously presented items. In other studies, responses were required to all items, including repeats (Hamberger & Friedman, 1992; Karayanidis, Andrews, Ward, & McConaghy, 1993; Swick & Knight, 1997). In every study, older participants showed robust repetition effects that were either of comparable magnitude and duration as those of young participants (Rugg et al., 1994) or were larger and more prolonged (Friedman et al., 1992; Friedman, Hamberger, et al., 1993; Hamberger & Friedman, 1992; Karayanidis et al., 1993; Swick & Knight, 1997). Furthermore, no study showed any evidence for an interaction between age and interitem lag. These findings strongly suggest that in contrast to many direct measures of memory (for a review, see Light, 1991), ERP repetition effects in indirect tasks do not diminish with increasing age. The independence of these effects from the neural and cognitive systems supporting explicit memory is further attested by two reports of reliable ERP repetition effects in persons with dementia of Alzheimer type (DAT), in whom explicit memory was severely impaired (Friedman et al., 1992; Rugg et al., 1994).

Only two studies have involved a comparison between ERP repetition effects in young and older participants in the continuous recognition task (Friedman, Berman, & Hamberger, 1993; Swick & Knight, 1997). In the study of Friedman, Berman, et al. (1993), words were repeated after 2, 8, or 32 intervening items. Although putative measures of the N400 were unaffected by the lag manipulation, repetition effects on the late positive component and a following positive slow wave diminished by equal measure in young and older participants as lag increased.

Swick and Knight (1997) investigated the ERPs elicited by words and pronounceable nonwords in a continuous recognition task in which items were repeated immediately, at a short interitem lag (1–3 items), or after a long lag (9–19 items). Contrary to the findings of Friedman, Berman, et al. (1993), Swick and Knight found that repetition effects were generally smaller in magnitude in the older group and that the effects were absent for items repeated at the longest lag. Swick and Knight suggested that their finding that long-lag ERP repetition effects were preserved in older participants in an indirect task, but not in an otherwise comparable direct task, supported the proposal that these two seemingly similar effects are associated with different forms of memory: implicit in the indirect task and explicit in the direct task. A similar suggestion has been made by Friedman (1995).

The goal of the present study was to address further the issues of the functional similarity of ERP repetition effects obtained in direct and indirect tasks, and the sensitivity of these effects to increasing age. Groups of young and older participants were tested in two tasks that differed largely with respect to their instructions and response requirements. The indirect task closely resembled those used by Friedman et al. (1992) and Rugg et al. (1994) to study ERP repetition effects in older individuals and persons with DAT. The direct task resembled that used by Friedman, Berman, et al. (1993) and Swick and Knight (1997; see also Rugg & Nagy, 1989).

Method

Participants

A total of 32 individuals participated in the study. The 16 young participants were drawn from a population of hospital employees and the 16 older participants were recruited from an over-60s exercise class. All participants reported that they were in good health and that they were free from medication active for the central nervous system. The groups were matched on full-scale IQ as estimated by the National Adult Reading Test (NART; Nelson, 1982) and on years of full-time education. These and other characteristics of each group are summarized in Table 1.

ERP Tasks

Overview. The participants performed two tasks, one indirect and one direct, in two separate test sessions. For most participants, the two sessions were separated by 1 week. The minimum separation between the sessions was 2 days and the maximum was 2 weeks.

Stimuli and list structure. A pool of 912 English nouns were selected, along with an additional 80 animal names. The animal names and the nouns varied in length between three and seven letters ($M = 5.0$ letters for both). The animal names had a mean frequency of occurrence of 5.4 per million, and the nouns had a mean frequency of occurrence of 16.3 per million, according to the Kucera and Francis (1967) word corpus.

In the indirect task, 80 of the items in a list were animal names (targets). In the lists employed for the direct task, these items were replaced by 80 nonanimal filler words selected at random from the initial pool of 912 words. Items from these conditions did not repeat. For both tasks, some of the items drawn from the remaining 832 words were repeated at one of two interitems lags (80 repetitions at each lag). Short lag repetitions were words that were repeated after one intervening item, and long lag repetitions were words that were repeated after a mean of 10 (range 8–12) intervening items. Because the total list length was 496 items, the probability of repetition was .16 at each of the two lags.

To construct the lists for the indirect task, two sequences were generated, each consisting of a different pseudorandomly determined ordering of experimental conditions (first presentations, short lag repetitions, long lag repetitions, targets). The sequences were constructed such that no item repeated across any of the seven rest breaks, which occurred after approximately every 65 trials. From the 832-word pool, 416 words were randomly selected to be used with one of the sequences and the remaining 416 words were used with the other sequence. These items were used to construct two lists by randomly allocating the words to the different experimental conditions (first presentations, short lag repetition, long lag repetition) and randomly allocating the 80 animal name targets to the appropriate positions within the lists. Another pair of lists was then generated, one for each sequence, by reversing the allocation of items to repetition condition (e.g., if *towel* had been a short lag repeat in one of the lists, it was repeated over the long lag in the other list).

Table 1. *Characteristics of the Young and Older Participants*

Characteristic	Young	Older
Age (years)		
M	24.2	67.6
Range	19–29	62–74
NART score		
M	123	123
Range	115–131	112–131
Education (years)		
M	14.9	13.2
Range	12–17	9–18
Handedness	15 right	15 right
Sex distribution	10 women, 6 men	12 women, 4 men

Note: NART = National Adult Reading Test.

The four lists thus constructed for the indirect task were modified for use in the direct task by replacing each animal target with a filler item. Thus, for each task, two independent sequences of conditions and items was available, and within each sequence items were counterbalanced with respect to whether they were repeated over a short or long lag. An appropriate rotation of lists and tasks across the participants in each group ensured that each sequence and each critical (repeating) item occurred equally frequently in each task and repetition condition and also ensured that each participant was exposed to a different combination of items and sequences for each task.

Words were presented visually on a television monitor (white on black) for a duration of 500 ms. The stimuli subtended a vertical angle of approximately 0.3° and a maximum horizontal angle of 1.5°. In both the indirect and direct tasks, a fixation point was continuously displayed on the screen other than for the period beginning 122 ms prior to stimulus onset and ending 1,000 ms after stimulus offset. Stimulus onset synchrony (SOA) in the indirect task was 3.1 s. As in previous studies (e.g, Rugg & Nagy, 1989; Rugg et al., 1991), SOA in the direct task varied because of the employment of a constant interval (2 s) between the response made on a given trial and the onset of the stimulus on the subsequent trial. This procedure was used to accommodate the anticipated variability in response times on this task both between and within participants. In practice, the SOA typically ranged between approximately 3 and 4.5 s.

Procedure

Indirect task. Following electrode application, participants were seated in front of the television monitor and were given a thumb switch to hold in their preferred hand. They were informed that they would see a sequence of words appearing one word at a time, that they should silently read each word, and that they should respond by squeezing the switch as quickly and as accurately as possible whenever the word was the name of an animal. An animal was described as "a living thing that is not a human being or a plant." Participants were further instructed to maintain fixation on the asterisk and to avoid blinking whenever the asterisk was absent from the screen. After delivery of the instructions, participants were given 30 practice trials with items different from those used in the experimental list proper. Responses faster than 200 ms or slower than 1,700 ms were treated as errors.

Direct task. Participants were seated in front of the monitor with the index finger of each hand resting on the button of one of two microswitchs, which were mounted on a response panel situated on the lap. They were informed that they would see words appearing on the screen one at a time. The instructions were to respond to each word as quickly and as accurately as possible, pressing one of the buttons when a word appeared for the first time and the other button when a repeated word was presented. The hand used for each response was alternated across participants. As in the indirect task, the participants were instructed to attempt to minimize blinks and other eye movements during the period in which the fixation asterisk was absent from the screen. Participants practiced the task with a 30-item practice list before the start of the experimental list. Responses faster than 200 ms or slower than 5 s were classified as errors.

For both tasks, words were presented in blocks of approximately 65 items. A short rest break was provided between each block.

ERP Recording

ERPs were recorded from 14 scalp sites using tin electrodes. Thirteen electrodes were embedded in an electrode cap (Electro-Cap International, USA), and were sited according to the 10-20 system (Jasper, 1958) at Fz, Cz, Pz, lateral frontal (50% of the distance from F3 to F7 and from F4 to F8), lateral temporal (50% of the distance from C3 to T3 and from C4 to T4), and lateral parietal (50% of the distance from P3 to T5 and from P4 to T6) sites, and at O1 and O2. The remaining electrode was situated on the right mastoid process. All electroencephalogram (EEG) recordings were referred to the left mastoid process. ERPs were algebraically reconstructed off-line to represent recordings with respect to a linked mastoid reference. Electrooculograms (EOG) were recorded from a bipolar pair of electrodes placed on the outer canthus of the right eye and on the supraorbital ridge of the left eye. All channels were recorded with a bandpass of 30–0.03 Hz (3 dB points) and were sampled at a rate of 6 ms/point for an epoch of 1,536 ms beginning 102 ms before stimulus onset.

In both tasks, ERPs were formed to first and second presentations of repeated words by averaging all error-free trials. When 16 or more trials from a task were contaminated by blink artifact, the participant's data for that task were subjected to a correction procedure to remove the artifact statistically. This procedure was based on a combination of the approaches advocated by O'Toole and Iacono (1987) and Semlitsch, Anderer, Schuster, and Presslich (1986) and was applied to most participants in each group (indirect task: 15 older, 13 young; direct task: 16 older, 12 young). For participants in whom this procedure was not adopted, trials contaminated with blink or other EOG artifacts were rejected.

Results

Preliminary Analyses

Preliminary analyses were conducted to test whether the behavioral measures or the ERPs associated with first presentations differed according to whether these items were subsequently repeated after the short or the long interitem lag. As expected, the analyses revealed no evidence of such differences. Accordingly, the data from first presentations were collapsed over lag for the purposes of the main analyses.

Behavioral Performance

The performance measures described below are based on responses to all available trials, not merely those contributing to the ERPs.

Indirect task. Accuracy and reaction time (RT) measures for this task are summarized for each group in Table 2. The t tests (with p levels adjusted for inhomogeneity of variance) showed no difference between the groups in target detection rate, but the older participants made significantly more false-positive responses, $t(30) = 2.71$, $p < .01$. In addition, the older participants were slower to respond to the targets, $t(30) = 4.57$, $p < .001$, and showed greater trial-by-trial variability in their target responses $t(30) = 3.48$, $p < .005$.

Table 2. *Performance Data from the Indirect Task for the Young and Older Participants*

	Young	Older
RT (ms)	643	809
SD	72	126
RTSD	121	168
SD	39	38
%Correct	95.7	94.2
SD	3.9	5.5
%False positive	1.6	3.9
SD	1.6	2.9

Note: Values listed are reaction time (RT) and standard deviation of reaction time (RTSD) for correct responses, percentage of correct target detections, and percentage of false-positive responses.

Direct task. The proportion of correct responses for the three critical item types (new, short lag repeat, long lag repeat) are shown in Table 3. A 2 (group) × 2 (lag) analysis of variance (ANOVA) on hit rates revealed a significant effect for lag, $F(1,30) = 45.62$, $p < .001$, reflecting lower levels of accuracy at the longer lag, but no effect for group or for the Group × Lag interaction. A t test contrasting the two groups' correct rejection rates was not significant. Analyses of the index pHit–pFalse alarm, a robust measure of sensitivity (Snodgrass & Corwin, 1988), corroborated these findings by revealing a significant lag effect,

Table 3. *Performance Data from the Direct Task for the Young and Older Participants*

	Young	Older
Short lag repeats		
%Correct	91.6	89.0
SD	8.8	9.4
RT	722	779
SD	98	102
RTSD	133	169
SD	38	53
Long lag repeats		
%Correct	73.1	68.5
SD	17.1	16.5
RT	774	898
SD	89	153
RTSD	136	222
SD	36	94
New items		
%Correct	97.7	90.7
SD	1.1	15.3
RT	701	763
SD	117	152
RTSD	152	172
SD	52	61

Note: Percent correct, reaction time (RT, in ms), and standard deviation of reaction time (RTSD) are shown for correct responses to short lag and long lag repetitions and for correct responses to items on their first presentation (correct rejections).

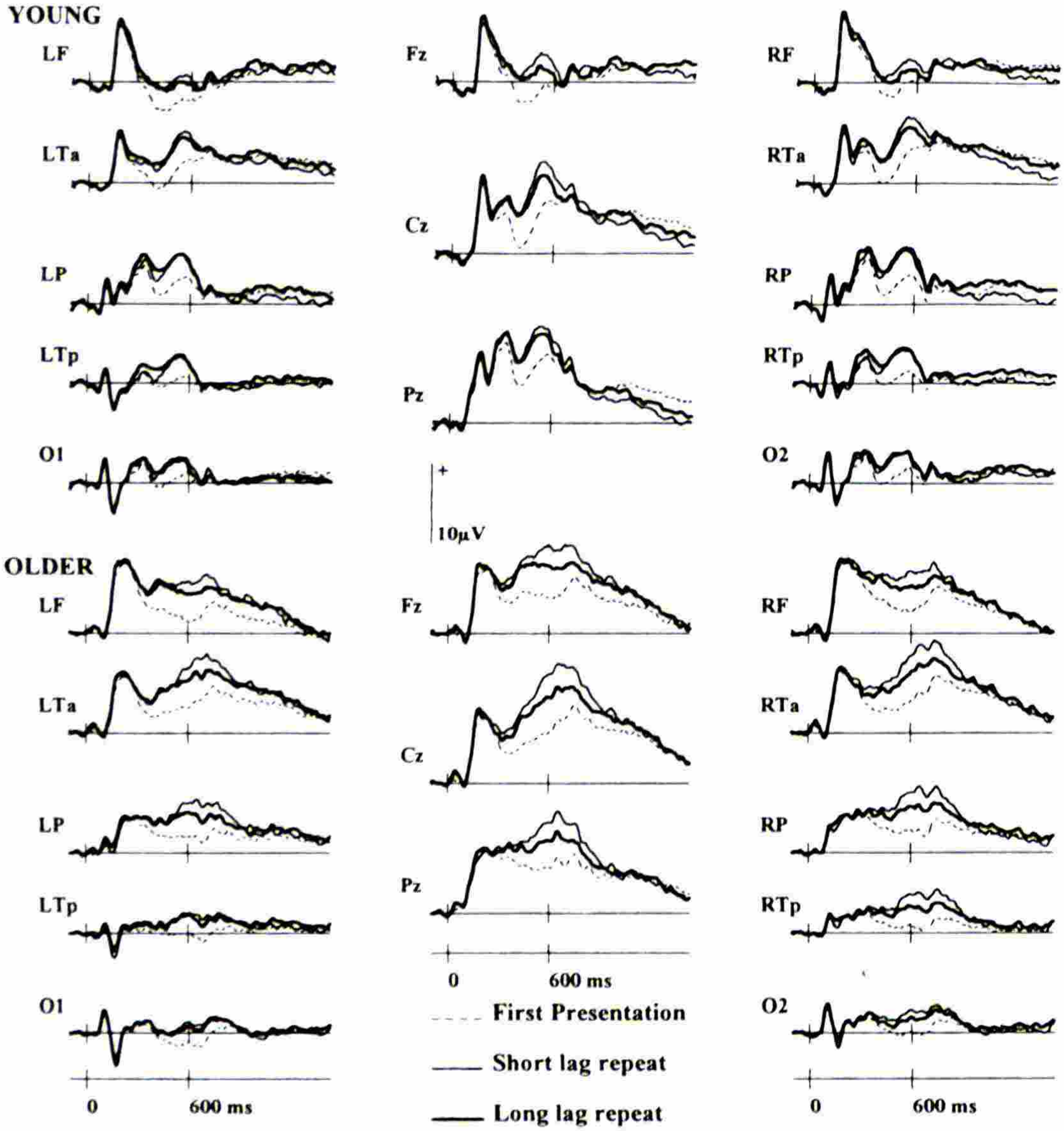

Figure 1. Grand average waveforms from the indirect task from the young (upper) and older (lower) participants for first presentations and for items repeating over the short and long interitem lags. Fz, Cz, and Pz refer to electrodes over frontal, central, and midline sites, respectively. LF, RF, LTa, RTa, LP, RP, LTp, RTp, LO, and RO refer to left and right frontal, anterior temporal, parietal, posterior temporal, and occipital sites, respectively.

$F(1,30) = 81.15$, $p < .001$, but no effect for group or for the Group × Lag interaction.

RTs for correct responses are shown in Table 3, along with means of the standard deviations of the RT distributions. A between-group t test comparing the RTs for correct rejections was not significant, as was the case for the comparison of the associated RT standard deviations. ANOVA of the RTs for the hits revealed significant effects for group, $F(1,30) = 5.76$, $p < .025$); lag, $F(1,30) = 44.29$, $p < .001$; and for the Group × Lag interaction, $F(1,30) = 6.79$, $p < .025$. Post hoc Tukey tests revealed that RTs for the long lag condition exceeded those for short lag repeats in both groups. The post hoc tests also indicated that the RTs for the two groups did not differ reliably at the short lag but that the older group responded significantly more slowly than did the young group to long lag repetitions. ANOVA of the standard deviations of the hit RTs revealed significant effects for group and lag and for their interaction, $F(1,30) = 10.61$, $p < .005$; $F(1,30) = 8.43$, $p < .01$; and $F(1,30) = 6.26$, $p < .025$, respectively. Tukey tests revealed that the standard deviations were higher for long lag than for short lag responses in the older group only. They further revealed that, for long lag responses, the older group's standard deviations exceeded those of the young group.

ERPs

Grand average waveforms of each group of participants are shown for the indirect task in Figure 1 and for the direct task in Figure 4. Corresponding subtraction waveforms are shown in Figures 2 and 5.

Analysis Strategy

As in a previous study (Rugg et al., 1994), the effects of repetition were quantified by measurement of single, broad latency regions straddling the latency of the peak amplitude of the effects in each group (300–600 ms for the young group, 400–700 ms for the older group). These measures are shown in Tables 4 and 5. The outcome

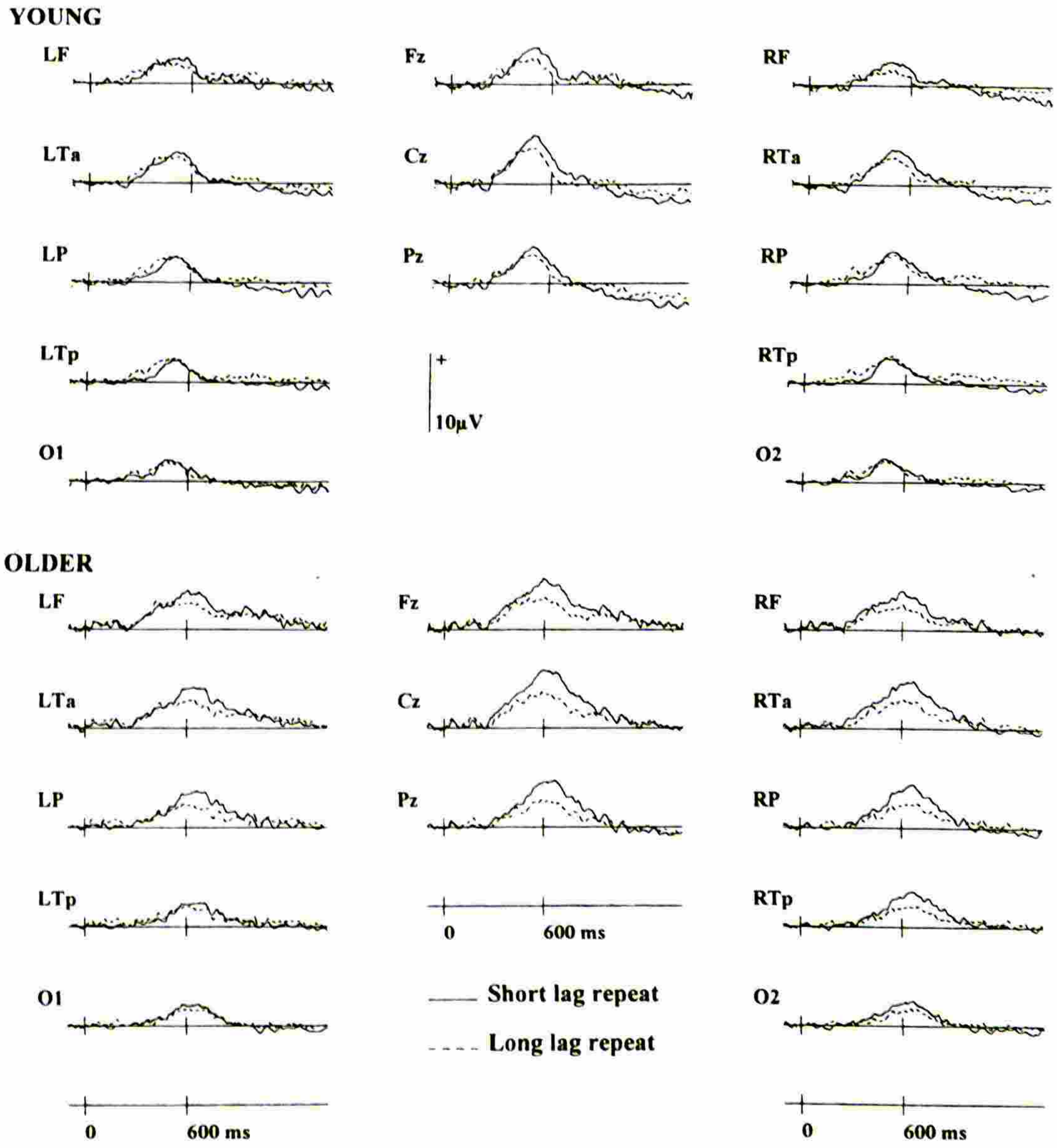

Figure 2. Grand average subtraction waveforms from the indirect task from the young and older participants. See Figure 1 caption for key to electrode sites.

of more detailed analyses, employing successive 100-ms latency regions, do not alter the conclusions drawn on the basis of the findings reported here. The analyses focus on between-group and between-task differences in ERP repetition effects. The analyses were performed on subtraction waveforms formed by subtracting the ERPs to first presentations from those to short and long lag repetitions. Thus, these analyses do not test for the reliability of repetition effects. They do, however, permit direct contrasts between the magnitude of the repetition effects according to group and task, independently of morphological or other ERP differences unrelated to the repetition manipulation.[1] The between-group analyses used separate ANOVAs of mean amplitude measures at the midline and lateral sites and included the factors of group, lag (short vs. long), hemisphere (analyses of lateral sites only), and electrode site. These and all other ANOVAs employed the Geisser–Greenhouse correction to compensate for the inflated risk of Type I error associated with nonsphericity (Winer, 1971) and only corrected *p* values are reported. A second set of between-group analyses was performed on the data from all electrode sites after the data had been rescaled to remove main effects of group and condition, allowing the scalp topographies of the repetition effects to be compared as a function of lag and group (McCarthy & Wood, 1985).

Subtraction waveforms were also used to estimate the onset latency of the different repetition effects for each group. These

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[1] Age-related differences in waveform morphology are irrelevant to the aims of this study, which focuses on differences in the magnitude and scalp distribution of the ERP modulations associated with word repetition. Age-related ERP differences that are insensitive to word repetition and thus not apparent in difference waveforms may or may not be of functional significance but obviously have little part in the study of repetition-sensitive processes. In any case, ruling out the possibility that such differences reflect some functionally uninteresting consequence of aging, such as changes in generator orientation caused by brain atrophy, is difficult.

Table 4. *Mean Amplitude (μV) of the ERP Repetition Effect in the Indirect Task at Short and Long Lags for the 300–600-ms Latency Region in the Young Participants and the 400–700-ms Region in the Older Participants*

	FZ	CZ	PZ	LF	LT	LP	T5	O1	RF	RT	RP	T6	O2
Short lag													
Young													
M	2.7	3.5	2.5	2.0	2.3	1.7	1.2	1.3	1.8	2.5	2.1	1.5	1.4
SD	2.1	3.1	2.9	1.8	2.0	2.4	2.0	1.9	1.5	1.7	1.7	1.7	1.8
Older													
M	4.1	4.8	3.6	3.0	3.2	2.6	1.6	1.6	3.1	3.8	3.1	2.5	1.8
SD	2.2	2.5	2.7	2.2	2.1	1.9	1.5	1.5	1.6	2.0	2.1	1.7	1.7
Long lag													
Young													
M	1.9	2.8	2.2	1.7	2.2	2.1	1.8	1.3	1.2	2.1	2.2	1.9	1.5
SD	1.6	2.1	1.9	1.8	1.6	1.7	1.5	1.5	1.6	1.3	1.5	1.5	1.4
Older													
M	2.9	3.1	2.2	2.6	2.5	1.9	1.6	1.3	2.1	2.5	1.9	1.6	1.2
SD	1.8	1.8	1.6	1.7	1.2	1.3	1.0	1.1	1.6	1.8	1.5	1.4	1.2

Note: Fz, Cz, and Pz signify midline frontal, central, and parietal sites. LF, RF, LT, RT, LP, RP, T5, T6, 01, 02 signify left and right frontal, anterior temporal, parietal, posterior temporal, and occipital sites.

were estimated by computing across-subject point-by-point t values on the subtraction waveforms for each task and lag. The onset of an effect was defined as the latency at which a t value attained significance at $p < .05$ or better and was followed by a minimum of 15 consecutive values (cf. Rugg et al., 1994).

As a prelude to the between-group analyses, we present the results of within-group and task contrasts for the ERPs elicited by first presentations and short lag and long lag repetitions. These contrasts assessed the reliability of each group's repetition effects in the two tasks directly and allowed a comparison of the present data with the findings from previous studies. For the sake of brevity and simplicity of exposition, these analyses are restricted to data from the electrode site manifesting the largest repetition effects in each task: Cz in the case of the indirect task and Pz for the direct task. The data took the form of a one-way ANOVA (factor of condition; first presentation vs. short lag repetition vs. long lag repetition), followed by planned pairwise comparisons (using the error term from the ANOVA), and Geisser–Greenhouse corrected degrees of freedom. The results of more detailed within-group analyses, using data from all electrode sites, were consistent with the conclusions drawn on the basis of the single-site analyses.[2]

Indirect Task

Within-group analyses. Repetition effects were evident in the waveforms from the young participants from approximately 250 ms poststimulus (upper part of Figures 1 and 2). The effects peaked at approximately 450–500 ms, had a Cz maximum, and returned to baseline between 600 and 800 ms according to site. The influence of interitem lag appeared to be minimal. Serial t tests revealed that the repetition effects begin at the Cz electrode site at 270 ms for the short lag condition and at 252 ms for the long lag repetitions. The amplitude of each participants' short and long lag effects at the Cz electrode is shown in Figure 3.

ANOVA of the 300–600-ms latency region of the ERPs from Cz revealed an effect for condition, $F(2,30) = 17.49$, $p < .001$, $\epsilon = 0.77$. The planned comparisons showed that the amplitudes for the short and long lag repetitions both exceeded that for first presentations, $t(23) = 5.59$ and 4.46, respectively, both $ps < .001$, but did not differ between themselves.

The bottom parts of Figures 1 and 2 show that the older participants also demonstrated sizeable repetition effects, which appear to have exceeded those of the young participants in both magnitude and duration. As measured by serial t-tests, the onset latencies of these effects were 276 ms and 288 ms for short and long lag repetitions, respectively. Consistent with the findings of Rugg et al. (1994), the peak of the repetition effects of the older group was around 500–600 ms poststimulus. The amplitude of each participant's effects at the Cz electrode is shown in Figure 3.

ANOVA of these data revealed a reliable condition effect, $F(2,30) = 45.90$, $p < .001$, $\epsilon = 0.75$. The planned comparisons revealed reliable differences between first presentations and both short and long lag repetitions, $t(23) = 9.45$ and 6.09, respectively, both $ps < .001$, and also between the two repetition conditions, $t(23) = 3.35$, $p < .005$. This last effect indicates that, among the older participants, the long lag repetition effect was reliably smaller than the short lag effect.

Between-group analyses. The mean amplitudes of the repetition effects for the young (300–600 ms) and older (400–700 ms) participants were contrasted. ANOVA of these data from the midline sites gave rise to significant effects of lag, $F(1,30) = 11.00$, $p < .005$, and electrode site, $F(2,60) = 8.43$, $p < .005$, $\epsilon = 0.70$, but not to an effect involving the factor of group. The first of these effects reflected smaller repetition effects in the long lag condition and the second effect their Cz maximum. ANOVA of the data from the lateral sites revealed significant interactions between lag and hemisphere, $F(1,30) = 6.64$, $p < .025$, and lag and site, $F(4,120) = 3.44$, $p < .05$, $\epsilon = 0.45$; these findings reflected larger lag effects over the right hemisphere and at frontal and temporal sites, respectively. The interaction between group and lag failed to reach significance, $F(1,30) = 3.83$, $p = .06$.

The failure to find evidence of a reliable interaction between group and lag is surprising in view of the findings from the within-group analyses, which revealed highly reliable lag effects in the older group, but no hint of such effects in the young group. As can

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[2] The results of the more detailed analyses referred to in this section are available from M. D. Rugg.

Table 5. *Mean Amplitude (μV) of the ERP Repetition Effect in the Direct Task at Short and Long Lags for the 300–600-ms Latency Region in the Young Participants and the 400–700-ms Region in the Older Participants*

	FZ	CZ	PZ	LF	LT	LP	T5	O1	RF	RT	RP	T6	O2
Short lag													
Young													
M	4.4	5.5	5.4	2.2	3.0	4.4	2.9	3.4	2.8	3.7	4.2	2.8	3.3
SD	2.7	2.8	2.9	2.1	1.9	2.3	1.7	2.3	2.3	2.2	2.1	2.1	2.1
Older													
M	1.2	1.5	2.1	0.1	0.8	2.1	1.5	1.6	0.9	0.9	2.4	1.8	1.7
SD	2.4	3.3	2.3	2.3	2.3	2.0	1.3	1.5	2.3	3.2	2.1	1.4	1.3
Long lag													
Young													
M	3.2	3.2	2.6	2.0	2.0	2.3	1.4	1.6	2.1	1.9	2.0	1.0	1.6
SD	2.7	2.6	2.4	2.9	2.1	2.1	1.7	2.0	2.7	2.3	2.2	2.0	2.0
Older													
M	−0.1	−0.8	−0.4	−0.5	−0.4	0.3	0.2	0.4	0.2	−0.6	0.1	0.2	0.4
SD	2.5	3.0	2.4	2.2	2.1	1.7	1.1	1.2	2.2	2.8	2.1	1.2	1.2

Note: The electrode sites are the same as for Table 4.

be seen in Figure 3, one reason for these seemingly paradoxical results may lie with the presence of an outlying participant in the young group, whose repetition effects are twice the size of those of any other participant, and show a large lag effect. With the data from this participant removed from the analysis, the between-group ANOVA for the lateral data, although not that for the midline measures, revealed a significant interaction between group and lag, $F(1,29) = 5.30$, $p < .05$.

Topographic analyses. ANOVA of the foregoing data sets after rescaling showed a significant main effect of site, $F(12,360) = 13.46$, $p < .001$, $\epsilon = 0.29$, but not to interactions between site and lag or group. Thus, the analysis provided no evidence that the topography of the repetition effects in the indirect task varied according to group or to lag.

One further analysis of the subtraction waveforms was conducted to determine whether, as suggested by Figures 1 and 2, repetition effects from the older participants were more prolonged. ANOVAs conducted on the mean amplitude of the 600–900-ms latency region revealed significant effects of group for both the midline and the lateral sites: midline, $F(1,30) = 21.31$, $p < .001$, lateral, $F(1,30) = 15.80$, $p < .001$, indicating that the older par-

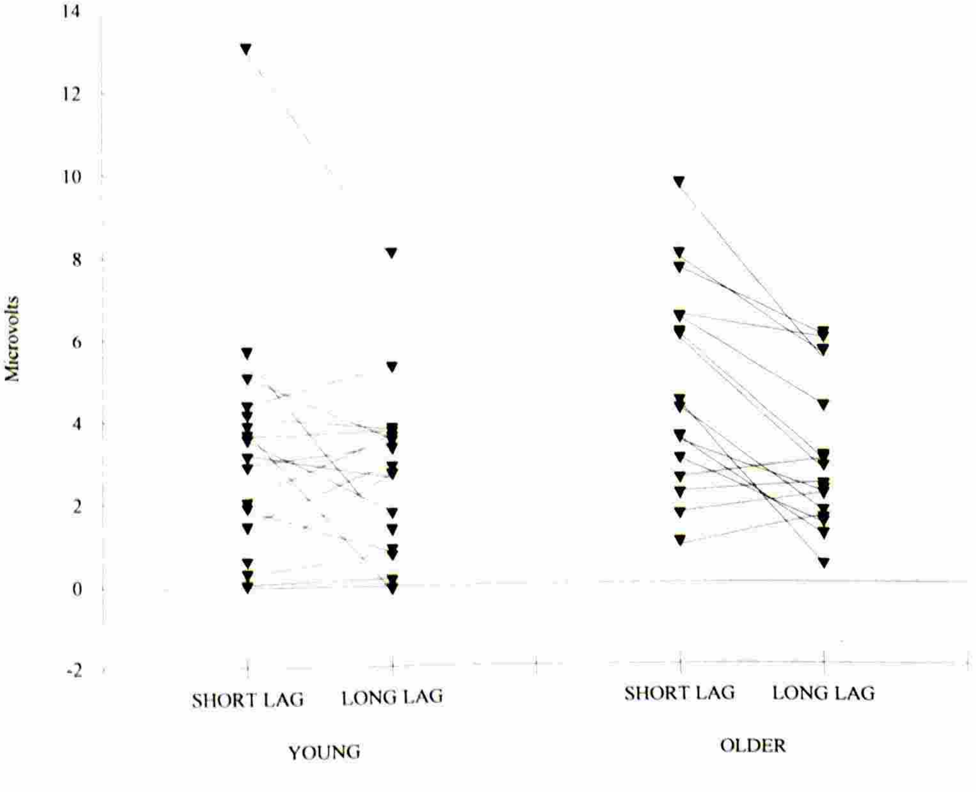

Figure 3. Amplitude of the repetition effect at the Cz electrode for short and long repetition in the indirect task, shown for each young (left) and older (right) participant. The lines connect each participant's data for the two lags.

ticipants' waveforms were indeed the more positive going in this region of the waveform.

Direct Task

Within-group analyses. As is evident from the top parts of Figures 4 and 5, repetition effects in the young group were prominent for both lags, beginning at around 250 ms and persisting until about 800 ms. In comparison to the effects associated with the indirect task, the direct repetition effects appeared to have a more posterior distribution and to be substantially smaller at the longer lag. According to the outcome of the serial t tests, the onset latency of the effects at Cz was 252 ms for short lag repetitions and 246 ms for the longer lag. The effects at the Pz electrode are shown for each participant in Figure 6.

ANOVA of these data gave rise to a main effect of condition, $F(2,30) = 41.40$, $p < .001$, $\epsilon = 0.78$. The planned comparisons revealed that all contrasts were reliable: first versus short, $t(20) = 9.41$, $p < .001$; first versus long, $t(20) = 5.44$, $p < .001$; short versus long, $t(20) = 3.98$, $p < .005$. Thus, although both repetition effects were reliable, the effect for the short lag exceeded that for the long lag.

The older group's ERP waveforms from the direct task are illustrated in the bottom parts of Figures 4 and 5. An effect was evident for short lag repetitions, but there was little sign of any such effect for the long lag repetitions. Instead, the waveforms elicited by the items repeated over this lag were more negative going than those to first presentations from approximately 600–900 ms poststimulus. Serial t tests failed to generate 15 consecutive significant values within the first 400 ms poststimulus at the Cz electrode site in the short lag condition or at any site in the long lag condition. The tests indicated that the short lag repetition effect first began at Fz at 330 ms. Figure 6 shows the effects at the Pz electrode for each member of the group.

ANOVA revealed a significant condition effect, $F(2,30) = 12.57$, $p < .001$, $\epsilon = 0.80$. Planned comparisons revealed a significant difference between first presentations and short lag repetitions, $t(24) = 3.91$, $p < .005$, and between short lag and long lag repetitions, $t(24) = 4.67$, $p < .005$, but no differences between first

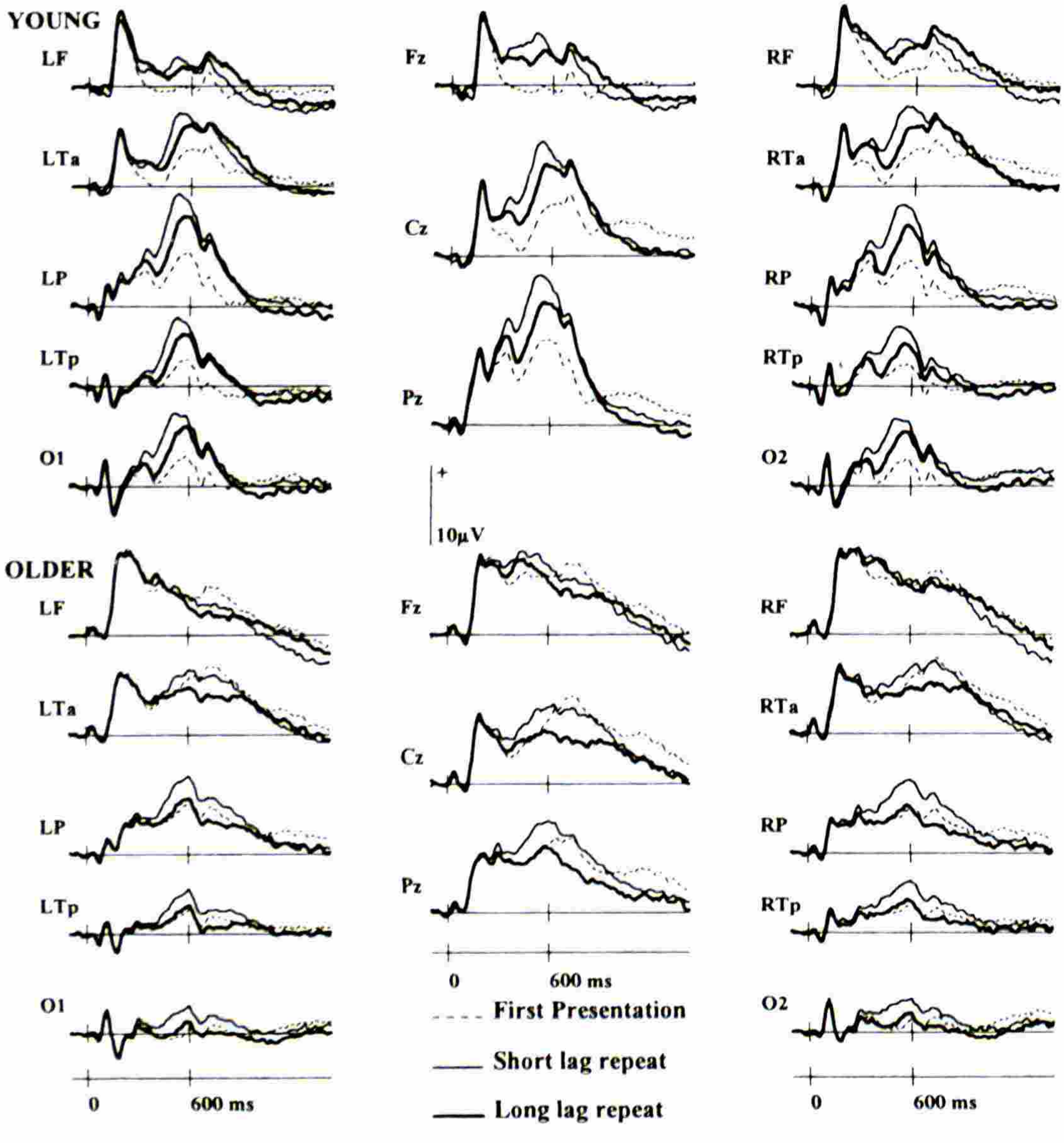

Figure 4. Grand average waveforms from the direct task from the young (upper) and older (lower) participants for first presentations and for items repeating over the short and long interitem lags. See Figure 1 caption for key to electrode sites.

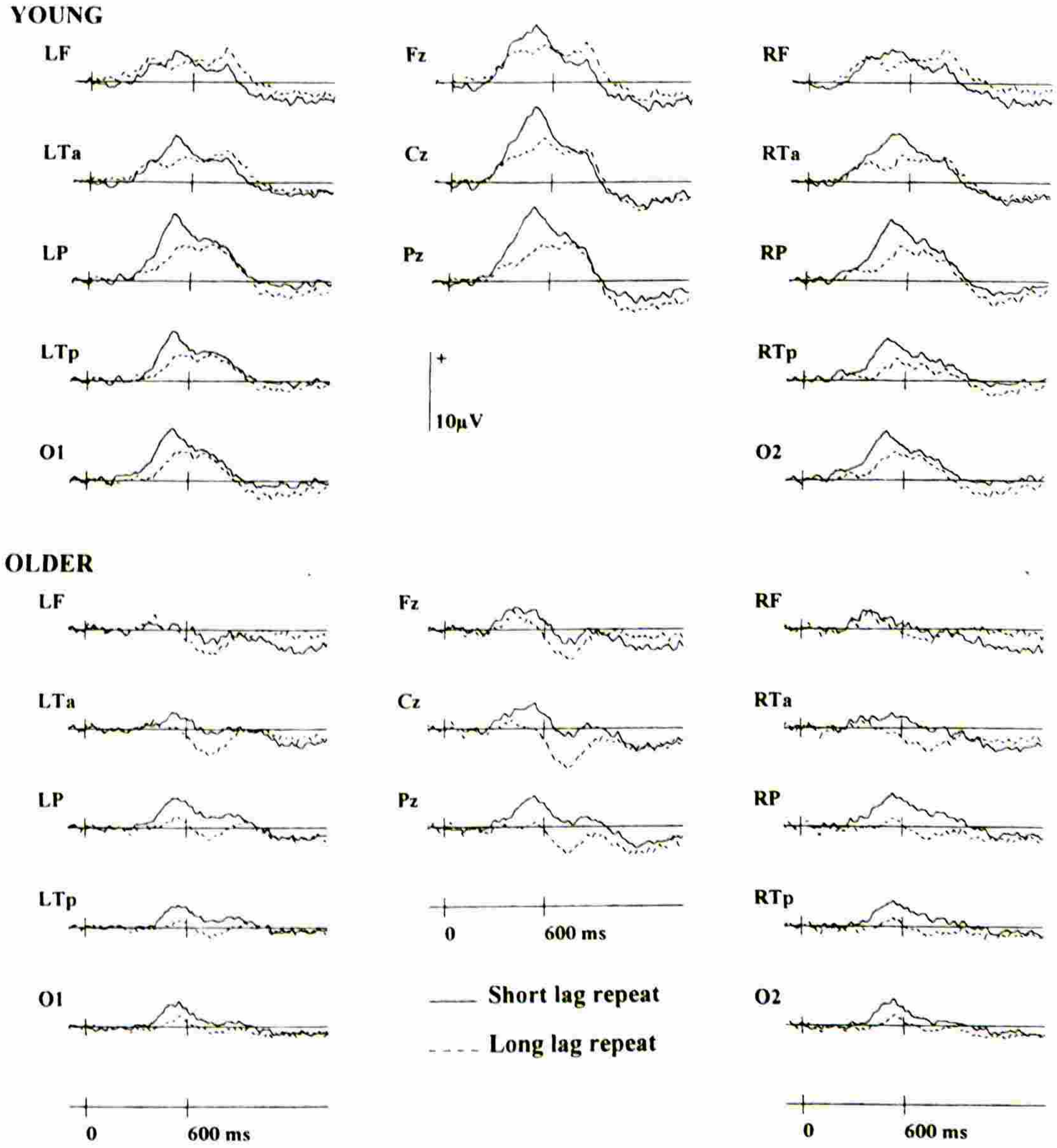

Figure 5. Grand average subtraction waveforms from the direct task from the young and older participants. See Figure 1 caption for key to electrode sites.

presentations and long lag repetitions. For this task, therefore, only the short lag repetitions showed a reliable repetition effect in the older participants.

Between-group analyses. ANOVA of the two groups' repetition effects from the midline electrodes revealed significant effects for group, $F(1,30) = 17.06$, $p < .001$, lag, $F(1,30) = 67.33$, $p < .001$, and for the interaction between lag and site, $F(2,60) = 11.23$, $p = .001$, $\epsilon = 0.61$. The results indicated that the repetition effects were of smaller magnitude in the older group's waveforms, and at the longer of the two lags, and that the lag effect was largest at posterior electrodes. ANOVA of the data from the lateral electrodes showed the same three effects for group, $F(1,30) = 11.85$, $p < .005$, lag, $F(1,30) = 86.68$, $p < .001$ and Lag × Site, $F(4,120) = 6.55$, $p < .025$, $\epsilon = 0.30$. The effect of group again arose because of smaller effects in the data for the older group and, for both groups, at the longer lag. The interaction between lag and site arose because the differences between the lags were greater at the parietal and temporal electrodes than at frontal and occipital sites.

In light of the absence of a reliable long lag repetition effect in the older group, between-group topographical differences were investigated for the short lag repetition condition only. ANOVA of the rescaled data revealed a main effect of electrode site, $F(12,360) = 6.88$, $p < .001$, $\epsilon = 0.29$, but no evidence of an interaction between group and site, suggesting that the topography of the short lag repetition effects did not change according to group.

Across-Task Analyses

Analyses were conducted to compare the magnitude and the topography of the repetition effects obtained in the two tasks directly. In each case, these analyses were restricted to the short lag condition because of the failure to find a reliable long lag effect for the direct task in the older group. First, ANOVAs were conducted on the magnitude of each group's repetition effects in the two tasks. For both midline and lateral measures, these ANOVAs revealed significant interactions between task and group: (midline, $F(1,30) = 17.57$, $p < .001$, lateral, $F(1,30) = 16.53$, $p < .001$. These findings arose because the young group's repetition effects

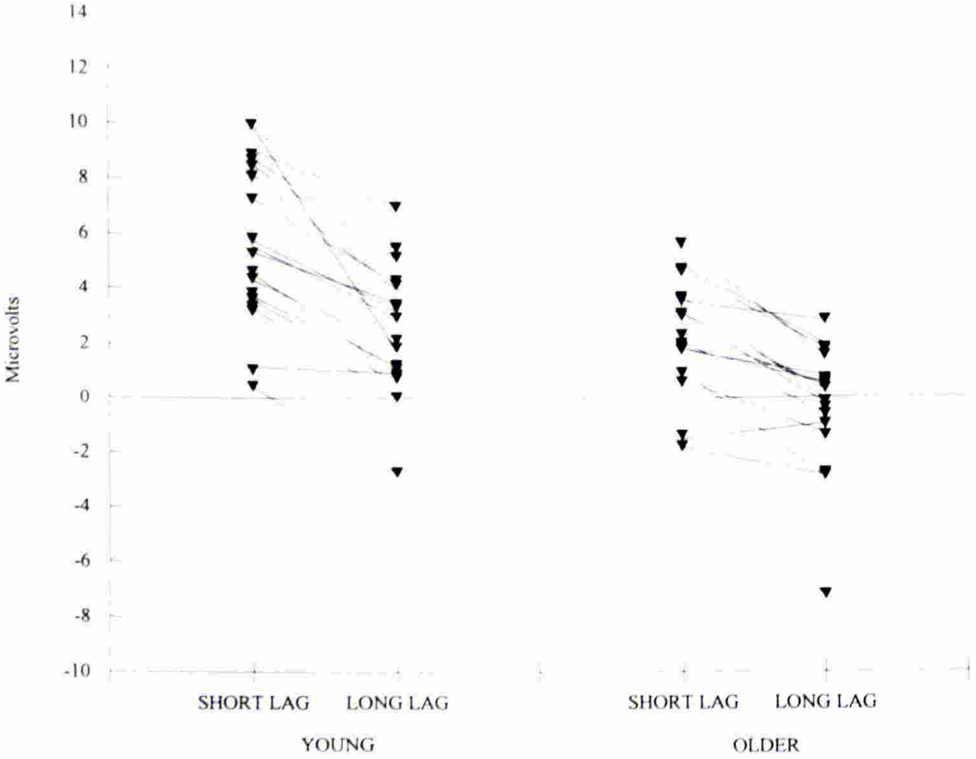

Figure 6. Amplitude of the repetition effects at the Pz electrode for short and long repetition in the direct task, shown for each young (left) and older (right) participant. The lines connect each participant's data for the two lags.

were larger in the direct than in the indirect task (collapsed over all sites, 4.19 μV vs. 2.33 μV for direct and indirect tasks, respectively), whereas the opposite was true for the older group (1.50 μV vs. 3.38 μV).

ANOVA of the rescaled data from the two tasks revealed no effects involving the factor of group but did give rise to a significant Task × Site interaction, $F(12{,}360) = 6.55$, $p < .001$, $\epsilon = 0.31$. This interaction appears to reflect more posteriorly distributed repetition effects in the direct task than in the indirect task. To confirm this impression, a second ANOVA was conducted on the data from the frontal sites, the anterior temporal and Cz electrodes, and the parietal sites, using the factors of group, task, electrode chain (midline, left hemisphere, right hemisphere), and site (frontal, middle [anterior temporal/Cz] and parietal). This ANOVA revealed only one effect involving the task factor, a Task × Site interaction, $F(2{,}60) = 12.54$, $p < .001$, $\epsilon = 0.73$. As can be seen in Figure 7, this interaction arose because the repetition effects in the direct task were parietally distributed, in contrast to the more anterior distribution of the effects in the indirect task.

Summary of ERP Analyses

Several of the most important findings from the foregoing analyses are evident in Figure 8. They can be summarized as follows. In both the young and older groups, reliable repetition effects were found in the indirect task at short and long lags. In the older participants only, these effects were smaller at the longer of the two lags. In the direct task, reliable effects were again found for both lags in the young group, although these effects were signif-

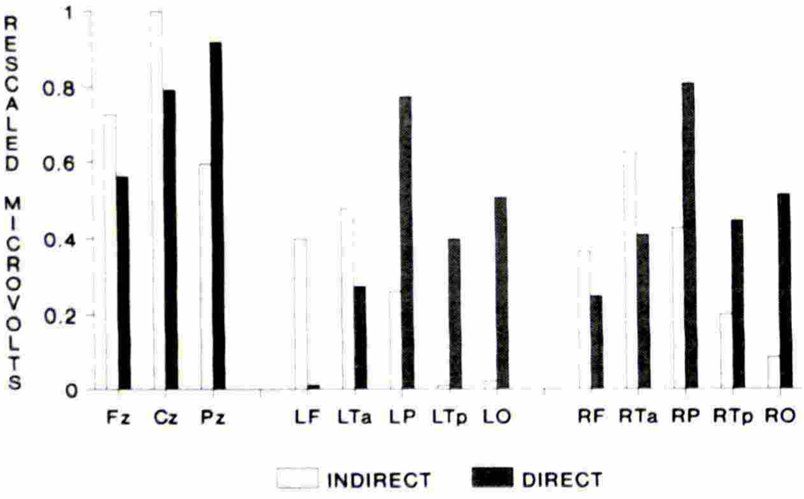

Figure 7. Rescaled amplitudes of the short lag repetition effects from the two tasks at each electrode site collapsed over participants.

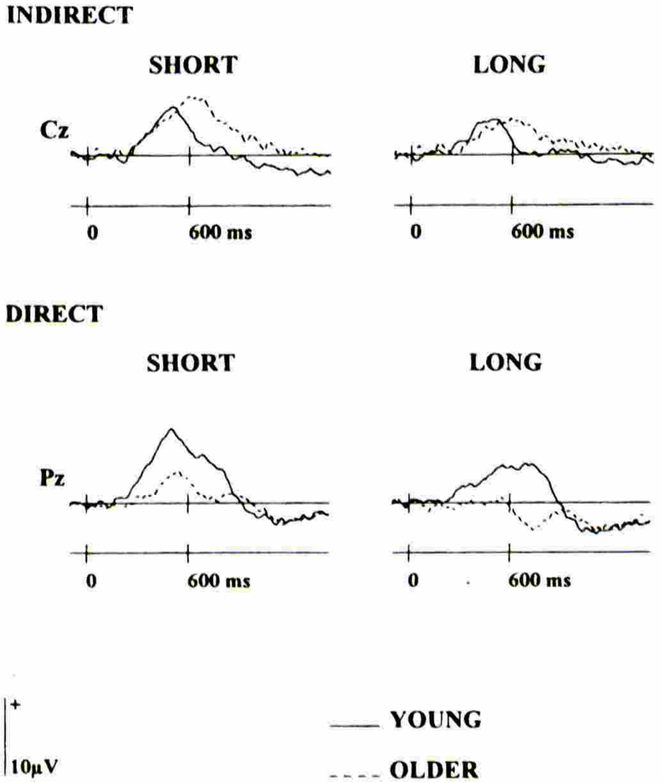

Figure 8. Grand average subtraction waveforms from the Cz electrode (indirect task) and the Pz electrode (direct task) overlaid by participant group and shown separately for the short and long lag conditions of each task.

icantly smaller at the longer lag. In the older group, repetition in the direct task gave rise to a reliable effect only for the short lag. No evidence was found for age-related differences in the topography of the repetition effects; both groups demonstrated more posteriorly distributed effects in the direct task. The relative magnitudes of the repetition effects in the two tasks differed according to group: The young group's effects were larger in the direct than in the indirect task, whereas the opposite was the case for the older participants.

Discussion

In both tasks, performance measures differentiated the young and the older participants. In the indirect task, the accuracy of target detection was very similar, but there was a reliable tendency on the part of the older participants to make more false-positive responses. In addition, target RT and across-trial RT variability were both substantially greater in the older participants.

In the direct task, the two groups showed equivalent ability to discriminate between repeated and unrepeated items, although a ceiling effect in the young participants may have restricted the true difference in correct rejection rates. Although RT and RT variability did not differ reliably between the groups either for correctly detected new words or for correctly detected short lag repeats, responses from the older participants to the long lag repeats were slower and showed greater across-trial variability. These results are consistent with previous findings that age-related differences in continuous recognition memory performance increase with increasing interitem lag (Poon & Fozard, 1980). The differences between the groups in RT measures at the longer lag most likely reflect weaker memories and an attendant reduction in decision confidence on the part of the older participants. Presumably, had an even longer lag been used, these age-related RT differences would have been accompanied by a decline in hit rate, as reported by Friedman, Berman, et al. (1993).

The ERP findings from the young participants in the indirect task are consistent with those of several previous studies (Bentin & Peled, 1990; Friedman et al., 1992; Nagy & Rugg, 1989). Words repeated after both the short and the long lags elicited robust ERP repetition effects, which did not differ significantly in magnitude. These findings are of particular interest in light of the performance data from the direct task. The data from the direct task show that when the participants were required to detect repetitions explicitly, detection rate was some 20% lower at the longer lag than at the shorter lag, with every participant showing a lower hit rate at the longer lag. If these findings were extrapolated to the indirect task, they would imply that the ERP repetition effect found in that task would be unlikely to reflect memory processes associated with the explicit recognition of a repeated item. If such an association existed, the effect should have been smaller at the long lag, when fewer repeated items would have been recognized.

In marked contrast to the findings from the indirect task, in every young participant the ERP repetition effects from the direct task were smaller at the longer of the two lags. The different sensitivities to lag of the repetition effects in each task are particularly noteworthy given that in the direct task ERPs were formed exclusively from items that had been correctly judged as old or new. These findings raise the possibility that the ERP repetition effects in the direct task reflect processes that are associated with the ability to recognize repeated items explicitly and that these processes become less effective as interitem lag increases. There are, however, reasons for caution in accepting this proposal. The items eliciting the ERPs in the direct task were associated with speeded behavioral responses and thus are likely to have elicited a sizeable late positive (P300) component. The latency of this component is correlated with the time taken to categorize the eliciting stimulus (for a review, see Coles, Smid, Scheffers, & Otten, 1995), making its amplitude sensitive to the degree of across-trial jitter in categorization time. Furthermore, evidence suggests that, other factors being equal, P300 amplitude declines as categorization time increases (e.g., Magliero, Bashore, Coles, & Donchin, 1984). The contributions of these two factors—increased latency jitter and lengthened categorization time—to the lag effect in the young participants' ERP repetition effects in the direct task are difficult to determine. It is arguable, however, that they may have been slight. The measures of RT variability show no evidence for a difference in across-trial variability in decision time for recognition of repeating items at the two lags. And post hoc analyses indicated that the approximately 50-ms difference in mean RT between the lags was nonsignificant, suggesting that the time taken to categorize repeating items did not change with lag.

The finding of a lag effect in the direct task among the young participants is at variance with the results of previous studies (Rugg & Nagy, 1989; Swick & Knight, 1997), which showed no diminution in the size of ERP repetition effects between short and long lags (lags of 6 vs. 19 items and of 1–3 vs. 9–19 items, respectively). The reason for this inconsistency is unclear, but one possibility is that the inconsistency reflects the use of participants from rather different populations. Rugg and Nagy (1989) and Swick and Knight (1997) used students as their young group, whereas the young participants in the present study were recruited from a more heterogeneous population.

The ERP repetition effects in the indirect task in the older participants were large and highly consistent across participants. As has been reported previously (Friedman et al., 1992; Karayanidis et al., 1993; Swick & Knight, 1997; but see Rugg et al., 1994), these effects began at around the same latency as those in the young participants, but peaked somewhat later, and were reliably more sustained over time. The present findings, as with those of the previous studies, suggest that whatever the neural and cognitive processes reflected by these ERP effects, they remain unimpaired with increasing age. Rather, these processes seemingly tend to be enhanced in older participants. This enhancement may be a consequence of the greater difficulty of the task for the older participants, as shown by the group differences in the performance data. The greater difficulty may have caused these participants to devote more processing resources to each item, one reflection of which was a larger repetition effect (for other views, see Friedman, 1995; Karayanidis et al., 1993).

The findings from the indirect task for the older participants differ from those of previous studies in one important respect: ERP repetition effects in the present study were smaller at the long lag than at the short lag. As can be seen in Figure 3, this reduction was present in the data of 12 of the 16 participants. In light of its inconsistency with previous studies, this finding should be treated with some caution, particularly because direct evidence in its favor, in the form of a reliable Age × Lag interaction term in the between-group analysis, was of questionable reliability.

When compared with the young group, the older participants' repetition effects for the short lag condition of the direct task were smaller in magnitude and began almost 100 ms later. For long lag repetition in the direct task, the region of the older participants' waveforms occupied by the short lag repetition effect showed no reliable effect at all. Instead, a reversed effect was evident from approximately 600 ms onward. These findings are in close agreement with those of Swick and Knight (1997; but see Friedman, Berman, et al., 1993), who also reported that older participants' repetition effects in the continuous recognition task were absent or reversed when items repeated at the longest of the three lags used (which varied between 9–19 items). The lack of a similarly dramatic lag effect in their young participants led Swick and Knight to interpret their findings as evidence for an age-related impairment in the neural processes supporting long-term recognition memory.

The present findings do not entirely support Swick and Knight's proposal because the influence of interitem lag was, if anything, even greater in the young group than it was in the older group (the difference between short and long lag repetition at the Pz electrode was 2.9 μV and 2.5 μV for young and older participants, respectively). Thus, the age-related differences observed at the long lag may have reflected the same factors that were responsible for the differences found for short lag repetitions rather than processes engaged only at the longer lag. The reduced ERP effects at the longer lag in the older participants were also accompanied by marked increases in RT and RT variability. For reasons already discussed, this finding raises the possibility that the reduction reflects, at least in part, the influence of jitter and lengthened categorization time.

Irrespective of the reasons for the lag effects in the direct task, the fact remains that even at the short lag the ERP repetition effects from the young participants exceeded those of the older participants. Because RT and RT variability for responses to first presentations and short lag repeats did not differ reliably between the groups, these group differences in the short lag repetition effects are unlikely to be attributable to factors such as latency jitter. Thus, these differences may reflect age-related changes in neural and cognitive processes associated with the explicit recognition of repeated items, changes that are evident even when repetition is over intervals that are well within the compass of short-term memory.

The differences between the groups in their short lag repetition effects in the direct task stand in marked contrast to those found in the indirect task, in which the differences are in the opposite direction. This double dissociation between age and task is also evident in the outcome of the between-task comparisons: Whereas the repetition effects of the young group were found to be reliably greater in the direct task than in the indirect task, the older participants' effects showed a reliable difference in the opposite direction. Similar findings have been reported by Swick and Knight (1997). Although direct comparisons between the direct and indirect tasks in the present study may be confounded by the differing response requirements of the two tasks, this objection does not hold for Swick and Knight's study, in which responses were required to the critical items in both tasks. Given these differences in design, the congruence between the findings of the two studies testifies to the robustness of the double dissociation between task and age in ERP repetition effects.

How might this dissociation be explained? An important clue comes from the analysis of the scalp topography of the repetition effects from the two tasks. This analysis failed to reveal any evidence for age-related topographic differences in either effect, implying that equivalent populations of generators were responsible for the two effects in young and older participants. The topographic analysis did, however, indicate that the topography of the two repetition effects differed. As illustrated in Figure 7, the effects in the indirect task were more anteriorly distributed than those in the direct task, indicating that the generators responsible for the two effects are not equivalent. A plausible explanation for this topographic dissociation is that, as already suggested, the repetition effects from the direct task contain a larger contribution from a parietally distributed late positive component than do the effects from the indirect task, which instead mainly reflect the modulation of the N400 (for a review of this literature and a similar argument, see Rugg, 1995). By this argument, the Task × Age interactions in ERP repetition effects can largely be accounted for by supposing that the generators of the late positive component are more sensitive to increasing age than are the generators of the N400.

Why should the late positive component be so much more prominent in the direct task and so sensitive to increasing age? Two possible explanations exist that are not necessarily mutually exclusive. First, the emphasis placed by the demands of the direct task on explicit recognition of repeating items is likely to have led to a greater engagement of episodic memory than in the indirect task. Episodic retrieval of information is known to be associated with the enhancement of a late positive component, albeit one with a more asymmetrical scalp distribution than that shown in the present study. The smaller magnitude of the older participants' repetition effects may thus reflect a relative impairment in one or more of the processes supporting episodic memory, a proposal that is consistent with the large literature documenting an age-related decline in this form of memory (Light, 1991). If this proposal is correct, then the present findings indicate that the neural correlates of this decline can be detected electrophysiologically even when memory performance does not depend on episodic memory retrieval, as in the short lag condition of the direct memory task.

A second explanation for the reduction in the amplitude of the late positive component with age in the direct task makes no recourse to the mnemonic demands of the task at all. As already noted, task-relevant stimuli demanding a prompt response are known to elicit a parietally distributed P300 component (Coles et al., 1995). In a number of different paradigms, P300 amplitude has sometimes been reported to decline with age (for a review, see Kugler, Taghavy, & Platt, 1993). Thus, the age-related differences in ERP repetition effects found in the direct task may reflect more than just changes in processes specific to episodic memory. However, the scalp topography of the P300 has been reported to change with increasing age, becoming more equipotential over the midline (for a review, see Friedman, 1995). The absence of such an effect in the present data thus calls into question the extent that the posteriorly distributed late positive component identified in the direct task represents a "generic" P300 (if such exists) rather than neural activity more closely tied to memory function. Determining the relative contributions of memory-specific and more general processes to these age-related ERP differences should be an important goal for future research.

The proposal that the differing sensitivities to age of the ERP repetition effects from the two tasks is attributable to the late positive component (P300) cannot by itself account entirely for the present findings. It is also necessary to assume that the N400 component made a more substantial contribution to the older participants' repetition effects in the indirect task than it did in the direct task. Without this assumption, it is difficult to explain why these participants' repetition effects at the short lag were greater in magnitude in the indirect task. If the N400-mediated effects were of equal amplitude in the two tasks, then the additional contribution of the late positive component in the direct task, however paltry, would have meant that the repetition effect in that task would have exceeded the effect in the indirect task (as appears to have been the case for the young participants).

Why would N400-mediated repetition effects in the older participants differ according to task? One possibility is that the older participants were less likely than the young participants to encode the items in the direct task in terms of their lexical/semantic properties (a speculation supported by evidence that older individuals are less likely to engage spontaneously in "elaborative" encoding; e.g., Craik & Simon, 1980; Hashtroudi, Parker, Luis, & Reisen, 1989). In the indirect task, by contrast, the nature of the discrimination required between targets and nontargets would have ensured that both groups of participants encoded the items semantically. Previous studies using indirect memory tasks have demonstrated that the region of the ERP repetition effect presumed to reflect the modulation of the N400 is attenuated when processing is restricted to a "shallow" level (Rugg & Doyle, 1994; Rugg et al., 1988). Thus, the greater contribution of the N400 to the older participants' repetition effects in the indirect task may have reflected differences between the two tasks in the "depth" to which items were processed by these participants. If this argument is correct, it should be possible to attenuate the age-related differences in repetition effects in direct tasks by manipulations that force participants to process items semantically.

As discussed previously, the absence of lag effects in the young participants' repetition effects in the indirect task stands in contrast to effects of lag on their recognition memory performance. This dissociation was taken to suggest that ERP repetition effects may not depend on the explicit recognition of the repeating item. This suggestion is consistent with previous proposals, based on neuropsychological studies, that the ERP repetition effect in indirect tasks reflects some form of implicit memory (Friedman, 1995; Friedman et al., 1992; Swick & Knight, 1995). The present data from the older participants are, however, somewhat at variance with this proposal. Notwithstanding the need for caution in accepting these findings, the lag effect found for the older participants' repetition effects in the indirect task is accounted for most parsimoniously by assuming that the effect reflects a decline in the proportion of items recognized as having been previously presented.

That said, the older group's ERP repetition effects for long lag repetition in the indirect task are equivalent in magnitude to those of the young participants. The robustness of the older participants' repetition effects in this task, as opposed to the fragility of the effects in the direct task, clearly demonstrates that word repetition in these two tasks engages dissociable processes in these participants. According to the present arguments, some of these processes, possibly reflected by modulation of the N400 component, remain relatively intact with increasing age. By contrast, other processes, reflected by the modulation of one or more late positive components, are more sensitive to increasing age. Whether these processes support memory functions that show differential rates of age-related decline is an important question for future research.

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