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Immediate and delayed stimulus repetitions evoke different ERPs in a serial-probe recognition task

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Abstract

In this study we examined whether event-related potentials (ERPs) associated with stimulus repetition and recognition in a serial-probe recognition task were comparable to ERPs in other tasks that are more typically used to investigate old/new ERP effects. The experiment consisted of 320 trials in which a recognition probe followed a four-item memory set; 160 trials consisted of images depicting common objects that were easy to label (EL task), and 160 trials consisted of images depicting abstract patterns that were difficult to label (DL task). Nineteen participants indicated whether a probe that followed each memory set was or was not presented in the memory set. Half of the probes matched, and half did not match, an item in the preceding memory set. ERPs appeared to reflect two processes—one that differentiated between recently presented stimuli and other stimuli and another that distinguished between repeated stimuli and new stimuli. ERPs to recent probes were more positive than ERPs to other probes in the EL and DL tasks. ERPs to match (old) probes were more positive than ERPs to nonmatch (new) probes only in the EL task.

Descriptors: Old/new effects, ERP repetition effects, Serial position effects, Recognition, Visual memory, Recency effect, Event-related potentials

As the study of event-related potentials (ERPs) has matured, researchers have come to appreciate the intimate association between memory processes and ERPs (e.g., see Kutas and Van Petten, 1988). A substantial body of research has demonstrated that stimuli seen previously during an experimental task, "old" stimuli, evoke more positive ERPs than stimuli not seen previously, "new" stimuli, beginning approximately 250–300 ms after stimulus onset and continuing for at least another 300–400 ms (see Rugg, 1995, for review). Furthermore, these "old/new" ERP effects appear to reflect at least two distinct processes—an early process that is associated with the N400 component and a late process that is associated with the P3 component (e.g., Rugg, 1990; Rugg & Doyle, 1994; Rugg & Nagy, 1989; Smith & Halgren, 1989). Numerous hypotheses have been proposed to explain these old/new ERP effects, but the functional significance of the cognitive/neural processes that underlie these effects remains unclear (Rugg, 1995).

Serial probe recognition (SPR) tasks may be useful for examining memory processes that underlie old/new ERP effects. In SPR tasks, individuals are presented with a list of stimuli to re-member followed by a probe stimulus, and they must decide whether the probe was or was not presented in the memory set. Much of the extant research examining old/new ERP effects has used one of three types of tasks: (1) semantic tasks in which individuals either make word/nonword judgments or read words in sentence contexts; (2) list learning tasks in which individuals study a list of words and are then assessed for recognition memory; or (3) continuous recognition tasks in which individuals are presented with a sequence of stimuli and must judge whether each stimulus is old or new. SPR tasks may have certain advantages over tasks that have typically been used to examine old/new ERP effects. For example, both SPR and continuous recognition tasks are well suited for examining stimulus repetition that occurs within a short temporal duration (i.e., compared with list learning tasks), but SPR tasks may provide a better picture of recognition/retrieval processes than continuous recognition tasks. That is, the format of a continuous recognition task may require individuals to initiate parallel encoding and retrieval processes when they are exposed to a stimulus. The format of an SPR task, on the other hand, informs individuals whether encoding (i.e., presentation of memory set item) or retrieval (i.e., presentation of probe) is appropriate. Thus, SPR tasks can compare ERPs associated with retrieval processes when a probe matches (i.e., "old" stimulus) versus does not match (i.e., "new" stimulus) an item in the preceding memory set without confounding retrieval and encoding processes as may occur in continuous recognition tasks. This is a potentially important advantage because research suggests that cognitive/neural processes that help people encode information into memory influence the P3, which is one part of the old/new ERP effect (e.g., Fabiani, Karis, & Donchin, 1986, 1990; Karis, Fabiani, & Donchin, 1984).

Although there has been considerable SPR research examining the timing of neural/cognitive processes using ERP latency measures (i.e., "memory scanning" tasks, e.g., see Kutas, 1988; Polich, 1996; for reviews), there has been relatively little SPR research examining the strength of neural/cognitive processes using ERP amplitude measures. Chao and Knight (1996), however, examined the amplitude of the ERP in a four-item SPR task and found evidence suggesting that there may be an ERP recency effect that differs from the old/new ERP effect. Specifically, they found that (1) during the latency range of the N400 (350–450 ms), probes that matched, compared with probes that did not match, an item from the memory set evoked more positive ERPs (i.e., old/new ERP effect); (2) during the latency range of the N400, probes that matched the last item from the memory set, compared with probes that matched an earlier item, evoked more positive ERPs (i.e., ERP recency effect); (3) during the latency range of the P3 (350–750 ms), probes that matched the last item from the memory set, compared with probes that matched an earlier item, evoked more positive ERPs (i.e., ERP recency effect). Crites, Devine, Lozano, and Moreno (1998) and Patterson, Pratt, and Starr (1991) also found some evidence for an ERP recency effect in SPR tasks. Like Chao and Knight (1996), Patterson et al. (1991) found evidence of an enhanced P3 (450–950 ms) to recent probes when the stimuli were auditory numbers but not visual numbers or auditory musical notes (Chao & Knight, 1996, used auditory sounds as stimuli). Alternatively, Crites et al. (1998) used visual images as stimuli in two separate SPR experiments and found evidence for an ERP recency effect during the latency range of the N400 (270–400 ms) but not during the latency range of the P3 (440–700 ms). Both Patterson et al. (1991) and Crites et al. (1998) focused on serial position effects and did not report match/nonmatch effects; thus, their findings provide evidence for an ERP recency effect but do not address the old/new ERP effect.

Although the results of Chao and Knight (1996), Crites et al. (1998), and Patterson et al. (1991) differ slightly, their findings suggest two ways that SPR tasks may help elucidate the memory processes that impact the ERP. First, SPR tasks may reveal an ERP recency effect that is distinct from the old/new ERP effect. That is, all three studies suggested that recently encountered stimuli evoke more positive ERPs than stimuli encountered earlier. Research using continuous recognition tasks and semantic decision tasks suggests that ERPs evoked by stimulus repetition that occurs within approximately 15 min differ from ERPs evoked by stimulus repetition that occurs after a delay of more than 15 min (Rugg, 1990; Rugg & Nagy, 1989). Findings regarding stimulus repetition that occurs within short temporal delays (i.e., less than 1 min), however, are more mixed. A number of researchers have reported greater ERP positivity when there are short temporal delays, and/or few intervening items, between the first and second instance of a stimulus (e.g., Chao, Nielsen-Bohlman, & Knight, 1995; Karayanidis, Andrews, Ward, & McConaghy, 1991; Swick & Knight, 1997), whereas others have found that the ERP positivity to repeated stimuli is not affected by the temporal lag, and/or the number of intervening items, between the first and second instance of a stimulus (e.g., Friedman, 1990a, 1990b; Nagy & Rugg, 1989; Rugg & Nagy, 1989). Still other researchers have found mixed results within the same experiment depending on the stimuli and/or tasks that are used (e.g., Bentin & Peled, 1990; Berman, Friedman, & Cramer, 1991; Rugg, Mark, Gilchrist, & Roberts, 1997). These inconsistent results from continuous recognition tasks and semantic decision tasks may occur because other processes are operating in these tasks that partially obscure decreases in neural activation

that occur as the lag between the first and second stimulus presentation increases. Because there are presumably fewer concurrent processes in SPR tasks, these tasks may prove useful in examining this issue. Second, SPR tasks may prove useful in clarifying the nature of the cognitive/neural processes associated with the late old/new ERP effect. There is a growing consensus that recognition processes underlie the late old/new ERP effect, though the exact nature of these recognition processes is still uncertain (e.g., see Rugg, 1995; Van Petten & Senkfor, 1996). Chao and Knight (1996), however, found no evidence for a late old/new ERP effect in their four-item SPR task (i.e., excluding the ERP recency effect); that is, the N400 to match probes was more positive than to nonmatch probes (an early old/new ERP effect), but the P3 to match probes from early memory set positions was comparable in amplitude to the P3 to nonmatch probes (no late old/new ERP effect). The late old/new ERP effect has been very robust so it is important to replicate Chao and Knight's (1996) findings; but if the late old/new ERP effect does not occur in certain conditions, this finding may help reveal the nature of the memory processes that underlie late old/new ERP effects.

The objective of this experiment was to use an SPR task to investigate whether (1) there is an ERP recency effect that is distinct from the old/new ERP effect and (2) the old/new ERP effect extends into the P3 latency range of the ERP. Chao and Knight (1996) found evidence for an ERP recency effect during both the early and late periods of the old/new ERP effect (i.e., those associated with the N400 and P3, respectively); Crites et al. (1998) found evidence for an ERP recency effect during only the early phase; and Patterson et al. (1991) found some evidence for an ERP recency effect during the late phase (they did not examine the latency period before the P3). Thus, although previous findings using SPR tasks provide some evidence for an ERP recency effect, the previous research has obtained slightly different results with regard to the latency range of the ERP recency effect.

There were several significant differences between the previous experiments that may explain the different findings. Both Patterson et al. (1991) and Chao and Knight (1996) used subspan memory sets (five-item and four-item memory sets, respectively) in which all of the items could be held in short-term memory (STM) until the probe was presented, whereas Crites et al. (1998) used a supraspan memory set (12-items) that exceeded the capacity of STM. In addition, Patterson et al. (1991) and Chao and Knight (1996) obtained significant effects with auditory stimuli (numbers and sounds, respectively), whereas Crites et al. (1998) used images of common objects. In fact, Patterson et al. (1991) found no ERP effects when the stimuli were visual numbers or musical notes. The present experiment investigated ERPs evoked in a subspan SPR task, similar to that used in Patterson et al. (1991) and Chao and Knight (1996), but used visual stimuli comparable to those used in Crites et al. (1998) to maintain consistency with our previous research. Another potential explanation for the slightly different ERP recency effects in the previous SPR experiments may have been ease with which participants could attach a meaningful label to the stimuli. For example, Chao and Knight (1996) used musical notes as stimuli that may have been hard for participants to label, whereas Crites et al. (1998) used visual images that participants could easily label. To investigate whether this factor may be important, the present experiment used two types of visual stimuli, images depicting items that people can label easily and images that depict items that people cannot label easily. Finally, this experiment investigated the robustness of Chao and Knight's (1996) finding

that match/nonmatch (old/new) differences do not extend in to the P3 latency range of the ERP in a subspan SPR task.

Method

Participants
Participants were Introductory Psychology students at the University of Texas at El Paso who participated in partial fulfillment of a course requirement. All reported that they were right handed and in good health. Data from 19 participants (14 women and 5 men) were included in the analyses after data from 5 participants were excluded prior to the analyses. Data from participants were excluded because (1) technical problems occurred during data acquisition, (2) excessive physiological artifacts that could not be removed were present in the scalp electrodes, and/or (3) the participant's behavioral accuracy did not differ significantly from chance.

Stimuli
Two sets of experimental stimuli were employed in this study. The first set consisted of 360 images of common objects (e.g., bear, watermelon) chosen from a set of clip art images. These images depicted items that were easy to label (EL). The second set consisted of 360 abstract images consisting of various color and form patterns. These images depicted items that were difficult to label (DL). Each stimulus was presented twice as a memory set item during the course of the experiment.

Procedure
After arriving at the laboratory, participants were told that the experiment was investigating the electrical brain activity associated with memory. The experimenter explained the experimental procedures and asked participants to read and sign an informed-consent form. Participants then completed the Edinburgh Inventory to assess hand preference (Oldfield, 1971). Next, the experimenter prepared participants for electroencephalogram (EEG) recording. Participants were then seated in a comfortable, reclining chair approximately 0.5 m in front of the monitor on which the experimental stimuli were displayed. Before the experiment was initiated, the experimenter reviewed the procedures. Participants were told that they would see a sequence of four images followed by a probe image and that their task was to indicate, by pressing one of two keys on a keypad, whether the probe was or was not presented in the four-image sequence. The experimenter emphasized that both the accuracy and the speed of their responses were important. After these instructions, the experimenter initiated the experiment.

The experiment consisted of an EL memory task, which included only images that were easy to label, and a DL memory task, which included only images that were difficult to label. Ten participants engaged in the EL task and then the DL task, and 9 participants engaged in the DL task and then the EL task.[1] Each memory task consisted of 160 four-item SPR trials. After participants completed the 160 trials in the first task, they received a short break and then completed the 160 trials in the second task.

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[1] Initial analyses revealed that the order of the two memory tasks (i.e., DL–EL vs. EL–DL) influenced behavioral responses to the probes (generally participants were more accurate in the first task they performed relative to those who performed the same task second) but did not affect the ERPs. Because the principle focus of this study was on the ERPs, we did not include task order in the subsequent analyses and do not discuss it further.

Each of the four memory set images were presented for 0.5 s with an interstimulus interval of 0.6 s. Each probe image was presented for 0.5 s and appeared 1.6 s after the offset of the fourth memory set image. There was a 2.0-s response window that began at probe onset during which participants could respond to each probe. The intertrial interval between each SPR sequence was 3.0 s. Five types of probes were used—probes that matched an image presented originally in the first, second, third, or fourth position of the preceding memory set and probes that did not match an image in the preceding memory set. To equate the number of times that participants indicated that the probe was present versus absent in the preceding sequence, nonmatch probes were presented following 80 sequences and each of the four types of match probes was presented following 20 sequences (for a total of 80 match probes).

Data Acquisition and Reduction
Bioelectrical activity was recorded using two types of ECI Electro-Caps (Electro-Cap International, Inc., Eaton, OH), one type containing Ag/AgCl electrodes and one type containing Sn electrodes. EEG activity was recorded from 29 scalp locations. The scalp electrodes were referenced to either the right mastoid, Ag/AgCl caps, or the right ear, Sn caps; electrical activity was also recorded from the left mastoid/ear so a digital linked reference could be computed following data collection. A ground electrode was located between FPz and Fz electrode locations. Vertical electro-oculographic (VEOG) activity was recorded from the right eye by supraorbital and infraorbital electrodes. Electrodes located outside the outer canthi of the right and left eyes recorded horizontal electrooculographic (HEOG) activity. Electrical impedance at each recording location was reduced to less than 5 kΩ. Neuroscan amplifiers were used to amplify, filter (bandpass of DC-30 Hz), and digitize (200 Hz) the bioelectrical signals that were recorded continuously during the experiment.

A number of steps were taken to reduce and quantify the bioelectrical data. First, a digital average reference for linked ears/mastoids was calculated. Second, a regression procedure for removing ocular artifacts from the EEG recordings was applied to the continuous bioelectrical data (Semlitsch, Anderer, Schuster, & Presslich, 1986). Third, epochs associated with each probe (0.2-s prestimulus, 0.5-s stimulus, and 0.7-s poststimulus periods) were extracted from the continuous data. Fourth, the bioelectrical signal at each recording site within each epoch was baseline corrected to the mean of its 0.2-s prestimulus period. Fifth, epochs in which EEG activity at any electrode location exceeded ±150 μV were eliminated. Sixth, the EEG recordings over each recording site for each participant were averaged separately for each of the five probe types (i.e., probes presented originally in positions 1 through 4 and nonmatch probes) within each of the two memory tasks. EEG sweeps associated with incorrect responses were not included in averaged waveforms or the subsequent ERP analyses. The ERP waveforms, therefore, included only EEG sweeps that were associated with correct responses and free of physiological artifacts. Seventh, the averaged ERP waveforms were digitally low-pass filtered at 15 Hz.

Results

Behavioral Responses
The analysis of response accuracy revealed a significant memory task main effect, $F(1, 18) = 178.50$, $p < .001$, as participants were more accurate in the EL task ($M = 92.3\%$, $SE = 2.0$) than the DL

task ($M = 66.3\%$, $SE = 2.1$). The analysis also revealed a significant probe main effect, $F(4,15) = 17.31$, $p < .001$, and a significant Memory Task × Probe interaction, $F(4,15) = 17.03$, $p < .001$. As can be seen in Table 1, one likely reason for the significant Memory Task × Probe interaction was a ceiling effect for response accuracy in the EL task. That is, when participants engaged in the EL task, they were accurate at identifying all types of probes, and they identified the different types of probes equally well. Alternatively, when participants engaged in the DL task, they were more accurate at identifying nonmatch probes and probes from the fourth memory set position than probes from the first, second, or third memory set positions.

Findings from the analysis of response latency were generally comparable to those observed with response accuracy. There was a significant memory task main effect, $F(1,18) = 43.61$, $p < .001$, as participants responded more quickly in the EL task ($M = 966$ ms, $SE = 33$) than the DL task ($M = 1,142$ ms, $SE = 38$). The omnibus analysis also revealed a significant probe main effect, $F(4,15) = 23.12$, $p < .001$ (see Table 1). Bonferroni analyses of the probe main effect revealed that participants responded more quickly to (1) probes from the fourth list position than to all other probes, (2) probes from the third list position than to probes from the first and second list positions, and (3) nonmatch probes than to probes from the first list position.

ERP Waveforms

Early task effect (80–195 ms). Visual inspection of the ERPs evoked in this experiment revealed an unexpected difference between the amplitude of the ERPs in the DL task and those in the EL task (see Figure 1). Specifically, the amplitude of the ERPs in the DL task appeared more positive than those in the EL task from approximately 100 to 250 ms—a latency range that included a negative potential that peaked approximately 110 ms following stimulus onset (maximum peak at FZ) and a positive potential that peaked approximately 170 ms following stimulus onset (maximum peak at Pz). To investigate this ERP difference, we examined the average amplitude of the ERP from 80 to 195 ms.

The amplitude of the ERP during the 80–195-ms range was examined along the five midline scalp locations using a 2 (Memory Task) × 5 (Probe) × 5 (Sagittal) multivariate analysis of variance (MANOVA). This analysis revealed a significant memory task main effect, $F(1,18) = 40.57$, $p < .001$ (see Figure 1). The ERP evoked in the DL task ($M = 0.63$ μV; $SE = 0.56$) was more positive than the ERP evoked in the EL task ($M = -1.64$ μV; $SE = 0.51$). There was also a significant sagittal main effect, $F(4,15) =$
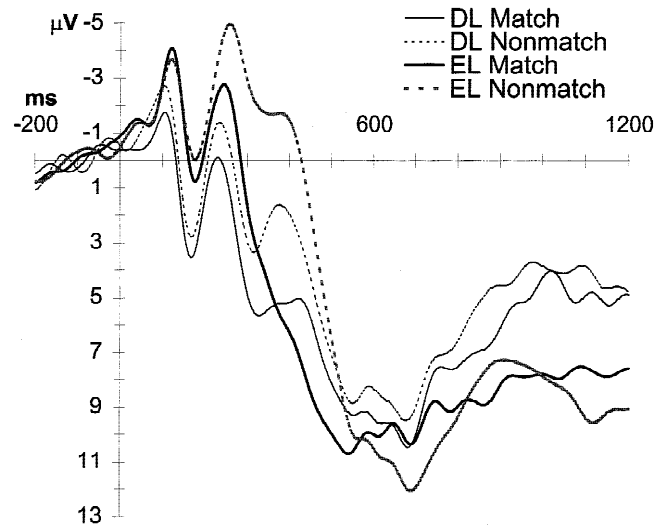

Figure 1. Average waveforms at Cz in the difficult to label (DL) and easy to label (EL) tasks. The graph depicts event-related potentials associated with correctly identified match probes (collapsed across the location of the probe in the memory set) and with correctly identified nonmatch probes. Positive is plotted down.

5.81, $p = .005$, as the amplitude of the ERP increased from the frontal to the posterior areas of the scalp ($M_{Fz} = -1.50$ μV, $SE = 0.69$; $M_{FCz} = -0.75$ μV, $SE = 0.68$; $M_{Cz} = -0.51$ μV, $SE = 0.61$; $M_{CPz} = -0.15$ μV, $SE = 0.50$; $M_{Pz} = 0.37$ μV, $SE = 0.71$).

To investigate whether the different memory tasks and/or probe types evoked ERPs with different scalp distributions during the 80–195-ms latency range, we examined the distribution of the ERP across four scalp regions by aggregating data from individual electrodes into four composite measures—left frontal (F3, F7, FC3, FT7), left parietal (P3, T5, CP3, TP7), right frontal (F4, F8, FC4, FT8), and right parietal (P4, T6, CP4, TP8).[2] The scalp distribution analyses included data from only 17 participants because data from 2 participants were excluded due to missing data at more than one electrode site in a scalp region. The scalp distribution of the ERP was examined using 2 (Memory Task) × 5 (Probe) × 2 (Lateral) × 2 (Sagittal) MANOVA. There was a significant sagittal main effect, $F(1,16) = 7.33$, $p = .016$, replicating the effect found in the midline analyses. In addition, there was a significant Memory Task × Sagittal interaction, $F(1,16) = 7.71$, $p = .013$, and a significant Memory Task × Lateral × Sagittal interaction, $F(1,16) = 13.84$, $p = .002$. The significant three-way interaction occurred because the difference between the amplitude of the ERP over the left and right frontal scalp regions was larger in the DL task ($M_{RF \& LF} = -0.22$ and -0.67 μV; Diff = 0.45) than in the EL task ($M_{RF \& LF} = -2.43$ and -2.50 μV; Diff = 0.07) but the difference between the amplitude of the ERP over the left and right

Table 1. *Mean Response Accuracy and Reaction Times to Probes in the Difficult to Label (DL) and Easy to Label (EL) Tasks*

	Accuracy (% correct)		Reaction time (ms)	
Probe	Difficult	Easy	Difficult	Easy
First	57.1 (3.25)	90.0 (3.36)	1,248 (37.4)	1,008 (38.5)
Second	51.8 (3.63)	90.3 (2.87)	1,221 (51.0)	1,029 (36.8)
Third	60.0 (3.55)	90.5 (2.62)	1,131 (42.3)	962 (39.6)
Fourth	84.2 (2.10)	95.3 (2.11)	999 (43.8)	881 (37.4)
Match	63.3 (2.61)	91.5 (2.46)	1,149 (38.2)	970 (36.6)
Nonmatch	77.7 (2.23)	95.9 (0.96)	1,113 (35.9)	968 (33.6)

Note: Values in parentheses are *SE*.

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[2]Because differences in the absolute amplitude of ERP components across experimental factors can lead to spurious interactions involving the spatial distribution of ERP components (McCarthy & Wood, 1985), we conducted analyses of standardized amplitude data in which differences in the absolute amplitude of ERP across experimental factors were eliminated (see Crites et al., 1998 for detailed description of procedures). In the text, we report main effects and interactions involving the scalp distribution of the ERP only when these effects were significant in the analyses of the standardized data. The analyses and means reported in the text are from the raw data.

parietal scalp regions was larger in the EL task ($M_{RP\&LP} = 0.86$ and -0.28 μV; Diff $= 1.14$) than in the DL task ($M_{RP\&LP} = 1.89$ and 1.12 μV; Diff $= 0.77$) (see Figure 2). Thus, the significant scalp distribution differences between the EL and DL tasks suggest that the set of neural generators that are active during the two tasks are not identical.

Early probe effect (270–400 ms). The extant literature has typically distinguished between an early old/new ERP effect that occurs during the latency range of the N400, approximately 250–450 ms, and a late old/new ERP effect that occurs during the latency range of the P3, approximately 500–900 ms. To examine the portion of the ERP typically associated with the early old/new effect, we examined the average amplitude of the ERP from 270 to 400 ms.

The amplitude of the ERP during the 270–400-ms range was examined along the five midline scalp locations using a 2 (Memory Task) $\times$ 5 (Probe) $\times$ 5 (Sagittal) MANOVA. This analysis

revealed a significant probe main effect, $F(4, 15) = 28.69$, $p < .001$, and a significant Memory Task $\times$ Probe interaction, $F(4, 15) = 5.92$, $p = .005$. To investigate this interaction, separate analyses were performed on the data from the DL task and the EL task, and the probe main effects from these two analyses were then examined using Bonferroni procedures. In the DL task, Bonferroni analyses of the significant probe main effect revealed that the ERP evoked by probes from the fourth memory set position was significantly more positive than the ERPs evoked by nonmatch probes and probes from the first and third memory set positions and marginally more positive than probes from the second memory set position (see Figure 3). In the EL task, Bonferroni analyses of the significant probe main effect revealed that (1) the ERP evoked by probes from the fourth memory set position was more positive than the ERPs evoked by all other probes (i.e., nonmatch probes and probes from the first, second, & third memory set positions), and (2) the ERP evoked by nonmatch probes was less positive than the ERPs evoked by all other probes (see Figure 4). Thus, the results of the EL task were consistent with previous research in revealing that previously seen stimuli evoked more positive ERPs during this latency range than "new" stimuli (i.e., an early old/new ERP effect), and they suggested that stimuli that are repeated immediately (i.e., from the fourth memory set position) are more positive than stimuli that are repeated after any stimuli intervene (i.e., a recency effect). The results of the DL task, however, revealed only a recency effect.

The midline analysis also revealed a significant sagittal main effect, $F(4, 15) = 7.46$, $p = .002$, and a significant Memory Task $\times$ Sagittal interaction, $F(4, 15) = 5.92$, $p = .005$. As can be seen in Figure 5, the Memory Task $\times$ Sagittal interaction occurred because the slope of the ERP from 270 to 400 ms across the midline of the scalp was greater in the DL than in the EL task.

The scalp distribution of the ERP from 270 to 400 ms was examined using 2 (Memory Task) $\times$ 5 (Probe) $\times$ 2 (Lateral) $\times$ 2
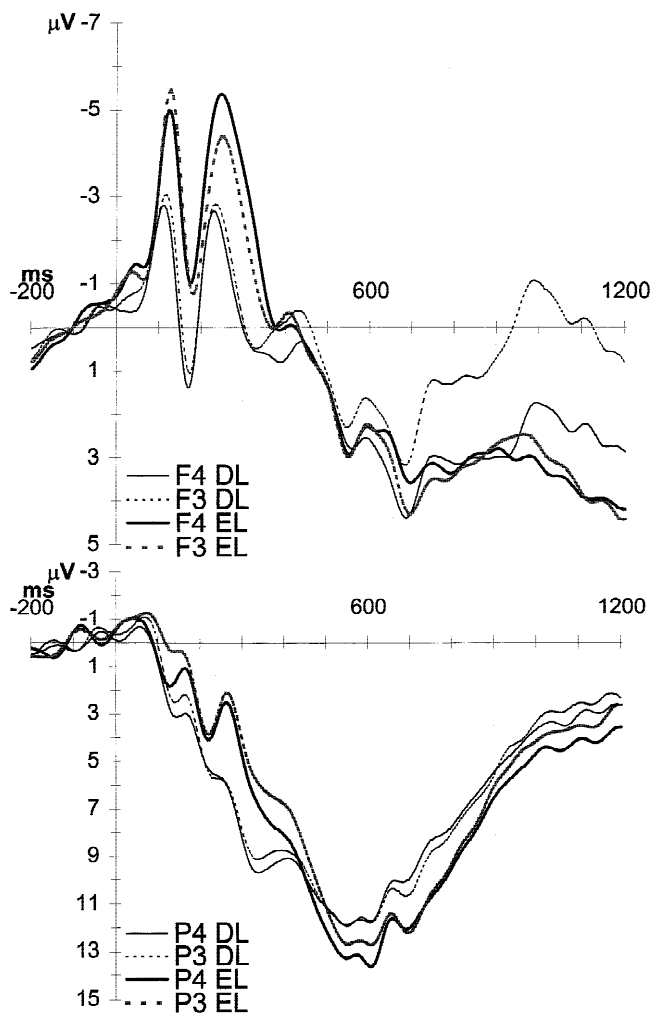

Figure 2. Top: Average waveforms in the difficult to label (DL) and easy to label (EL) tasks at representative left (F3) and right (F4) frontal scalp locations. Bottom: Average waveforms in the DL and EL tasks at representative left (P3) and right (P4) parietal scalp locations. The graphs depict event-related potentials associated with correctly identified probes (collapsed across match and nonmatch probes). Positive is plotted down.
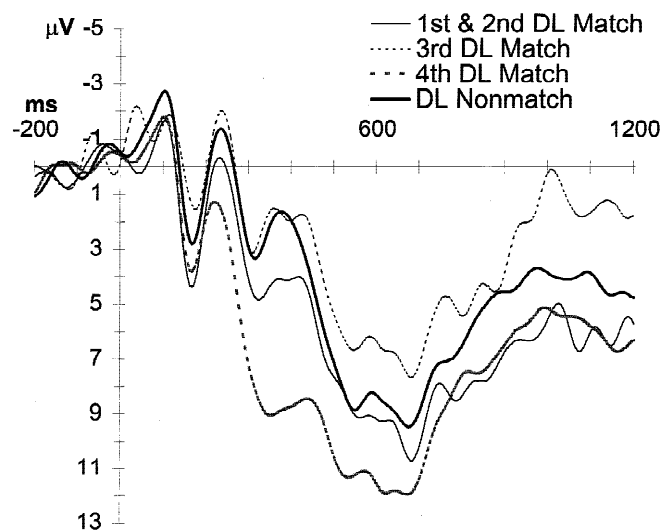

Figure 3. Average waveforms at Cz in the difficult to label (DL) task. The graph depicts the event-related potentials (ERPs) associated with probes that matched an item from the first and second, third, and fourth memory set positions and probes that did not match an item from the memory set. The ERPs from the first and second positions were very similar so, for presentational reasons, these two ERPs were averaged together and are presented as a single waveform in the graph. Positive is plotted down.

Figure 4. Average waveforms at Cz in the easy to label (EL) task. The graph depicts the event-related potentials (ERPs) associated with probes that matched an item from the first and second, third, and fourth memory set positions and probes that did not match an item from the memory set. The ERPs from the first and second positions were very similar so, for presentational reasons, these two ERPs were averaged together and are presented as a single waveform in the graph. Positive is plotted down.
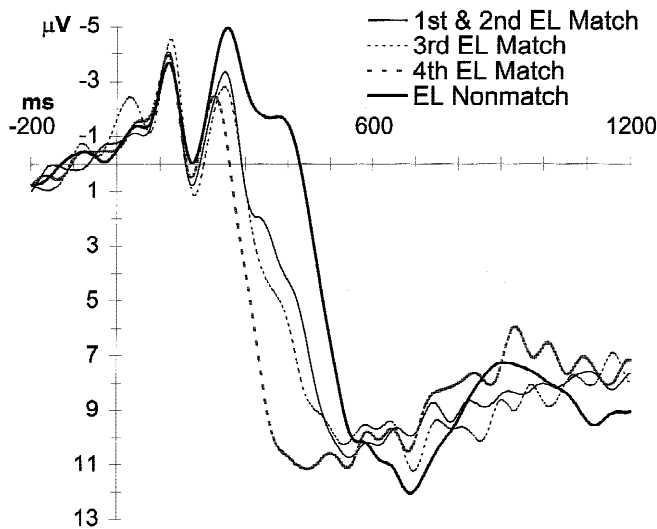
(Sagittal) MANOVA. As in the previous scalp distribution analysis, this analysis included data from only 17 participants. The analysis of the scalp distribution of the ERP revealed a significant sagittal main effect, $F(1,16) = 45.02$, $p < .001$, replicating the effect found in the midline analyses. There was also a significant Lateral × Sagittal interaction, $F(1,16) = 6.21$, $p = .024$. In the frontal areas, the ERP from 270 to 400 ms was more positive over
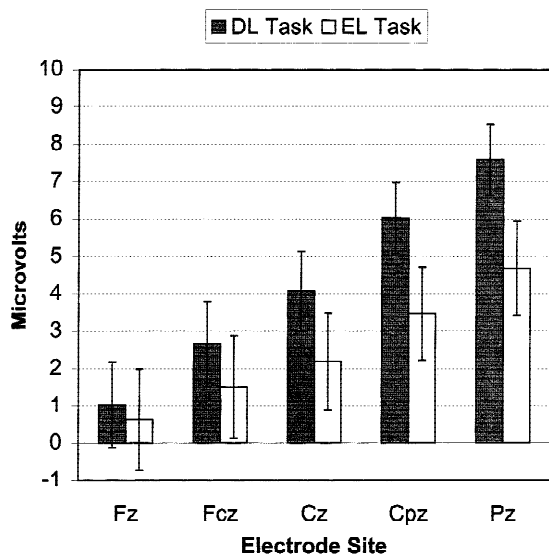

Figure 5. Amplitude of the event-related potential (ERP) from 270 to 400 ms across the midline of the scalp in the difficult to label (DL) and easy to label (EL) tasks. The figure depicts the significant Memory Task × Sagittal interaction for the ERP amplitude along the midline of the scalp.

the left ($M = 0.32$ μV; $SE = 0.97$) than the right ($M = -0.17$ μV; $SE = 1.07$) regions, but it was more positive over the right ($M = 6.44$ μV; $SE = 0.84$) than the left ($M = 5.51$ μV; $SE = 0.99$) regions in the parietal areas (see Figure 2).

Late probe effect (450–800 ms). To examine the portion of the ERP typically associated with the late old/new effect that is generally associated with the P3, we examined the average amplitude of the ERP from 450 to 800 ms along the five midline scalp locations using a 2 (Memory Task) × 5 (Probe) × 5 (Sagittal) MANOVA. The analysis revealed a significant probe main effect, $F(4,15) = 3.20$, $p = .044$, and a significant Memory Task × Probe interaction, $F(4,15) = 3.93$, $p = .022$. To investigate this interaction, separate analyses were performed on the data from the DL task and the EL task, and the probe main effects from these two analyses were then examined using Bonferroni procedures. In the DL task, Bonferroni analyses of the significant probe main effect revealed that the ERP evoked by probes from the fourth memory set position was significantly more positive than the ERPs evoked by probes from the first and third memory set positions (see Figure 3). In the EL task, the probe main effect was not significant; the ERPs evoked by probes in the various conditions, therefore, did not differ significantly (see Figure 4). Thus, there was no late old/new ERP effect in either the EL or DL tasks, but there was some evidence of an ERP recency effect in the DL task. Finally, there was a significant sagittal main effect in the omnibus analysis as the amplitude of the ERP increased from the frontal to the posterior scalp regions ($M_{\text{Fz}} = 3.58$ μV, $SE = 1.27$; $M_{\text{FCz}} = 6.83$ μV, $SE = 1.91$; $M_{\text{Cz}} = 9.02$ μV, $SE = 1.23$; $M_{\text{CPz}} = 10.98$ μV, $SE = 1.06$; $M_{\text{Pz}} = 11.40$ μV, $SE = 1.00$), $F(4,15) = 18.58$, $p < .001$.

The scalp distribution analysis revealed a significant sagittal main effect, $F(1,16) = 119.38$, $p < .001$, which is comparable to the effect observed in the midline analysis. In addition, there was a significant Probe × Lateral × Sagittal interaction, $F(4,13) = 10.24$, $p = .001$, and a significant Memory Task × Probe × Lateral × Sagittal interaction, $F(4,13) = 17.63$, $p < .001$. As can be seen in Figure 6, the amplitude of the ERP over the left and right scalp regions, in both the frontal and parietal areas, was fairly comparable for each probe. The significant Memory Task × Probe × Lateral × Sagittal interaction most likely occurred because the ERP to nonmatch probes in the EL task, but not the DL task, was larger over the left frontal region than the right frontal region. Figure 6 also depicts another aspect of the data that may have contributed to the significant four-way interaction. Specifically, the ERP to probes presented originally in the first memory set position in the DL task was slightly larger over the right frontal region than the left frontal region, whereas the ERP over the right and left frontal regions was more equivalent in the EL task.

Discussion

This experiment investigated whether an SPR task could provide information regarding the memory processes associated with stimulus repetition. To examine this issue, we presented visual images in a four-item SPR task and examined the ERPs evoked by probes that matched versus did not match an item from one of the four memory set positions. The stimuli used in each SPR trial were either images depicting common objects that were easy to label or images depicting abstract color and form patterns that were difficult to label. Other types of tasks, which are more typically used to investigate stimulus repetition, generally find that old/repeated stimuli evoke more positive ERPs from approximately 250 to 700 ms
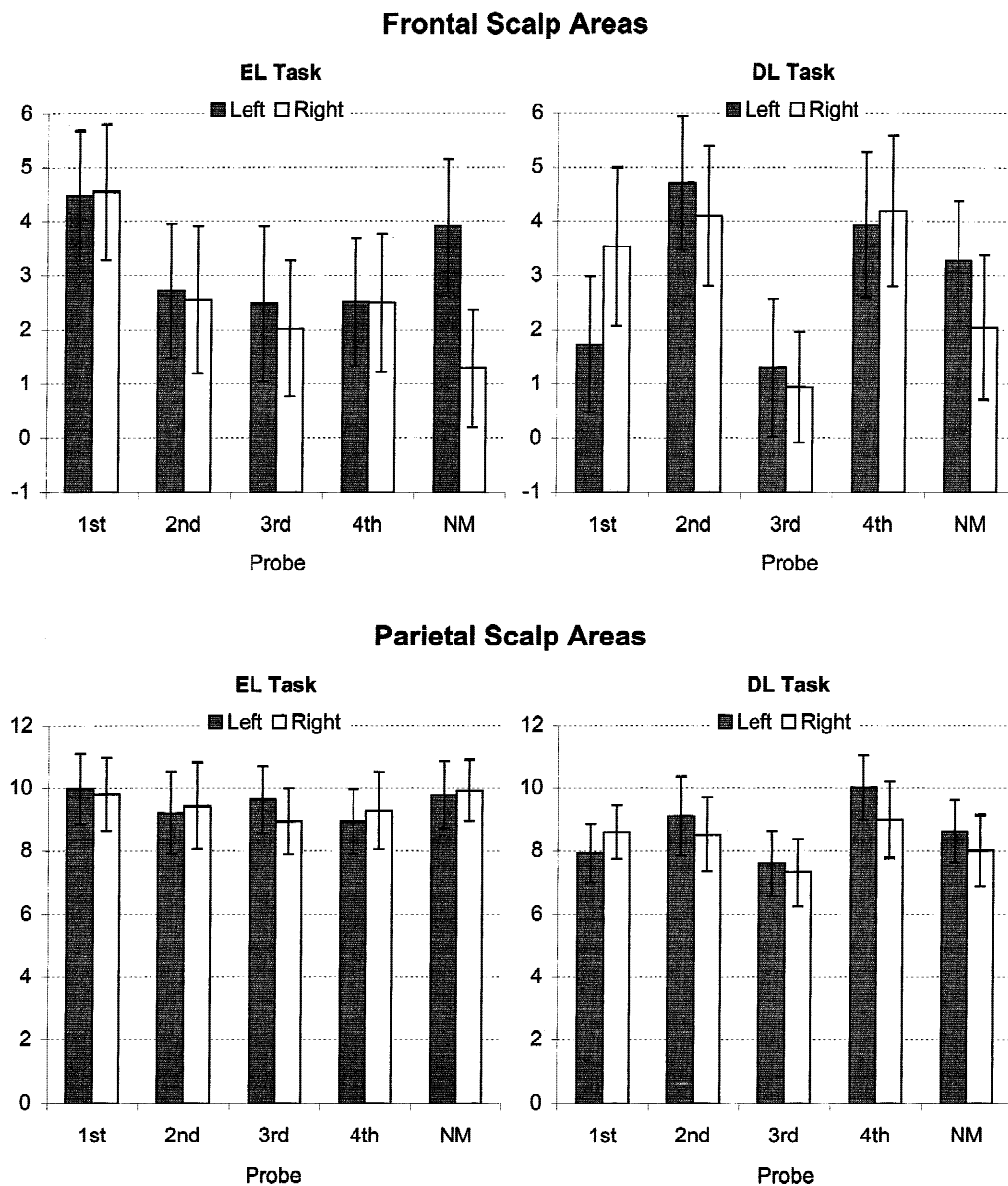
Frontal Scalp Areas

EL Task

DL Task

Parietal Scalp Areas

EL Task

DL Task

Figure 6. Amplitude of the event-related potential (ERP) from 450 to 800 ms over the lateral and sagittal scalp locations in the difficult to label (DL) and easy to label (EL) tasks. The figure depicts the significant Memory Task × Probe × Lateral × Sagittal interaction for P3 amplitude. The two graphs on the top reflect the average amplitude of the ERP from 450 to 800 ms over the left and right frontal scalp locations. The two graphs on the bottom reflect the average amplitude over the left and right parietal scalp locations. The graphs on the left depict data from the EL task whereas the graphs on the right depict data from the DL task. The different types of probes are on the abscissa of each graph, and the average amplitude of the ERPs in microvolts is depicted on the ordinate.

than new stimuli. The ERPs evoked in this SPR task appeared to reflect at least two processes—one that distinguished between repeated stimuli and new stimuli (old/new ERP effect) and one that differentiated between recently presented stimuli and all other stimuli (ERP recency effect).

The identification of an ERP recency effect in this experiment is an important contribution to the literature that has examined the impact of stimulus repetition on the ERP. Although previous research using SPR tasks provided suggestive evidence for an ERP recency effect, the effect observed in previous experiments was not identical (Chao & Knight, 1996; Crites et al., 1998; Patterson et al., 1991). The present experiment provides additional evidence for an ERP recency effect and suggests that characteristics of the stimuli

and/or task can impact the duration of the ERP recency effect, which may explain the previous inconsistent findings. That is, the ERP recency effect in the EL task occurred during the latency range of the N400 (270–400 ms) but did not extend into the latency range of the P3 (450–800 ms), whereas the ERP recency effect in the DL task began in the latency range of the N400 and extended into the latency range of the P3. Importantly, the present findings, along with the previous findings from SPR tasks, suggest that an ERP recency effect occurs only when the stimulus repetition occurs immediately (i.e., a delay of only a few seconds with no intervening items).

One reason previous research using continuous recognition and semantic decision tasks did not distinguish between the ERP re-

cency effect and the old/new ERP effect is because the research focused on the impact of STM and not on whether stimulus repetition was immediate. This focus on STM led to seemingly inconsistent findings. Research that compared stimulus repetition that occurred immediately versus after a delay generally found that ERPs evoked by immediately repeated stimuli were more positive (e.g., Bentin & Peled, 1990; Chao et al., 1995; Karayanidis et al., 1991; Swick & Knight, 1997; but see Nagy & Rugg, 1989, for an exception). Alternatively, research that compared stimulus repetition that occurred within STM, but not immediately, versus outside STM generally found that ERPs to repeated items were comparable in amplitude (e.g., Friedman 1990a, 1990b; Rugg & Nagy, 1989; Swick & Knight, 1997; but see Berman et al., 1991, and Rugg et al., 1997, for exceptions). Thus, sometimes the presence versus absence of an item in STM appeared to influence the amplitude of the ERP (i.e., when immediate repetition was contrasted with delayed repetition), and sometimes it appeared to not affect the amplitude of the ERP (i.e., when repetition occurred within vs. outside STM). The present findings help clarify the previous findings by demonstrating that immediate stimulus repetition influences the ERP.

The present findings also revealed an old/new ERP effect that occurred in the EL task but not in the DL task. Furthermore, the old/new ERP effect in the EL task occurred from approximately 270 to 400 ms and did not extend into the latency range of the P3. The present findings are interesting given that previous research has differentiated between an early old/new ERP effect (250–400 ms), which is associated with the N400 component, and a late old/new ERP effect (450–800 ms), which is associated with the P3 component (e.g., see Rugg, 1995; Rugg & Nagy, 1989; Smith & Halgren, 1989). Thus, the findings in the EL task (i.e., an early but not a late old/new ERP effect) provide additional evidence that the distinction between the early and late old/new ERP effects is meaningful. The failure to find a late old/new ERP effect in this experiment is interesting because (1) previous research identified factors that selectively eliminated the early, but not the late, old/new ERP effect and (2) there is a growing consensus that the late old/new ERP effect reflects successful memory retrieval (see Rugg, 1995, for review). Van Petten and Senkfor (1996) hypothesized that the P3 reflects the updating of STM with information from long-term memory (LTM) (see also Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991). This hypothesis may explain the nonsignificant late old/new ERP effects in the present experiment and in Chao and Knight (1996), because both experiments used subspan SPR tasks in which all of the stimuli could be stored in STM so there was no need to update STM with information from LTM. Although caution should be used when making inferences based on nonsignificant findings, the present findings in conjunction with Chao and Knight (1996) offer some evidence that stimulus repetition within STM does not lead to an enhanced P3 and thus suggest that SPR tasks may provide a means for better understanding the nature of the memory processes that underlie the P3.

The failure to find an old/new ERP effect in the DL task during the 270–400-ms latency range is consistent with previous research and theory that has associated the early old/new ERP effect with the N400. The N400 is thought to represent semantic activation that reflects the extent to which a stimulus is related to its context (see Kutas & Van Petten, 1988, 1994, for reviews). The early old/new ERP effect, therefore, is assumed to reflect reduced semantic activation to the second presentation of a stimulus. Rugg and Doyle (1994) hypothesized that the early old/new ERP effect should occur only for stimuli that are meaningful or that lead to the generation of unitized codes. The findings of the present experi-

ment are consistent with this hypothesis because an early old/new ERP effect was observed with images depicting common objects that individuals could easily label but not with images depicting abstract color and form patterns. The present experiment, which identified an ERP recency effect that is separate from the old/new ERP effect, may also help explain some findings that are apparently inconsistent with Rugg and Doyle's (1994) hypothesis. Begleiter, Porjesz, and Wang (1993), for instance, reported an old/new ERP effect that occurred with meaningless visual patterns, but their findings were with immediate stimulus repetition. The Begleiter et al. (1993) findings, therefore, may reflect the ERP recency effect and not the old/new ERP effect.

Thus far, we have discussed the ERPs in the DL and EL tasks as if they were generally equivalent; however, the two tasks elicited ERP waveforms that were very different during the 270–400-ms latency range. The ERPs in both tasks revealed a comparable set of early potentials—a negative potential (114 ms), a positive potential (170 ms), and a negative potential (234 ms).[3] In the DL task, these early potentials were followed by a positive potential (310 ms), a negative potential (371 ms), and then a late positive or P3 potential (610 ms). The ERPs evoked in the EL task, however, ascended from the second negative potential (234 ms) to the late positive or P3 potential (586 ms). The ERPs evoked in the DL task are comparable to ERPs observed in much of the previous research. Although the ERPs evoked in the EL task were more atypical, they were also comparable to ERPs in the literature, especially when there was a short lag between the initial and subsequent stimulus presentation (e.g., see Chao et al., 1995; Karayanidis et al., 1991; Rugg et al., 1997; Swick & Knight, 1997). The ERPs evoked in both tasks also appeared remarkably similar to those evoked in Crites et al.'s (1998) 12-item SPR task, which used stimuli comparable to those in the EL task. The ERPs evoked by recent probes (positions 10–12) in Crites et al. (1998) appeared similar to those evoked in the EL task. This similarity suggests that ERPs and memory processes associated with recognizing a meaningful probe that matches one of the four items in a four-item subspan SPR task are equivalent to the ERPs and memory processes associated with recognizing a meaningful probe that matches one of the last three items in a 12-item supraspan SPR task. Alternatively, the ERPs evoked by prime (positions 1–3) and middle (positions 6–8) probes in Crites et al. (1998) appeared similar to those evoked in the DL task. This second similarity suggests that the processes associated with recognizing a meaningless visual pattern after one to three intervening items in a four-item subspan SPR task are comparable to those involved in recognizing a meaningful visual stimulus after 4 to 11 intervening items in a 12-item supraspan SPR task.

The early ERP amplitude and scalp distribution differences (from approximately 80 to 195 ms) between the DL and EL tasks

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[3]Preliminary analyses examining each of the potentials independently revealed some evidence that the ERP recency effect began during this second negative potential (195–270 ms). The early ERP task effect, which was observed from 80 to 195 ms, however, was also present during this second negative potential. The latency range of this negative potential (195–270 ms), therefore, was not included in the analyses because it distorted the findings. That is, if it was included with the early latency range (average amplitude examined from 80 to 270 ms rather than from 80 to 195 ms), the findings implied an ERP recency effect during this early range. Alternatively, if the negative potential was included with the later latency range (average amplitude examined from 195 to 400 ms rather than from 270 to 400 ms), the findings implied a memory task effect during this latency range.

were an unexpected finding. Some previous research suggested that ERPs are more positive during this early latency range when participants selectively attend to certain physical characteristics of stimuli such as color (e.g., Smid, Jakob, & Heinze, 1999). This finding may explain the early amplitude differences because some participants commented during the debriefing that they focused on color in the DL task. The ERP differences occurring so early suggests that participants used different cognitive strategies within each task, which could have occurred easily because the DL and EL tasks were presented in distinct experimental sessions. This idea is further supported by the significant scalp distribution differences because these differences indicate that different neural generators were active in the two tasks (e.g., see Johnson, 1993; McCarthy & Wood, 1985).

Although SPR tasks have typically not been used to examine neural processes associated with memory and recognition (perhaps because these tasks require numerous stimulus presentations to obtain a single ERP recording), this experiment provides some evidence that SPR tasks may help reveal the memory processes that underlie ERPs. The present research suggests that stimulus repetition that occurs immediately may be distinct from stimulus repetition that occurs after even a single item intervenes between the first and second instance of a stimulus. That is, we have differentiated between an ERP recency effect (immediate repetition) and an old/new ERP effect (repetition after an intervening item or items). This finding reflects an important advancement over previous research that investigated old/new ERP, or ERP repetition, effects because immediate versus delayed repetition had been treated as equivalent. More research is needed to determine whether these effects are qualitatively different or whether the ERP recency effect is an exaggerated old/new ERP effect. This experiment also suggests that old/new P3 effects may not occur when stimulus repetition occurs within the capacity of STM, which may have important implications for theoretical accounts of the late old/new ERP effects.

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