Word and Nonword Repetition Within- and Across-Modality: An Event-Related Potential Study

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Abstract

The effects on event-related potentials (ERPs) of within- and across-modality repetition of words and nonwords were investigated. In Experiment 1, subjects detected occasional animal names embedded in a series of words. All items were equally likely to be presented auditorily or visually. Some words were repetitions, either within- or across-modality, of words presented six items previously. Visual-visual repetition evoked a sustained positive shift, which onset around 250 msec and comprised two topographically and temporally distinct components. Auditory-visual repetition modulated only the later of these two components. For auditory ERPs, within- and across-modality repetition evoked effects with similar onset latencies. The within-modality effect was initially the larger, but only at posterior sites. In Experiment 2, critical items were auditory and visual nonwords, and target items were auditory words and visual pseudohomophones. Visual-visual nonword repetition effects onset around 450 msec, and demonstrated a more anterior scalp distribution than those evoked by auditory-visual repetition. Visual-auditory repetition evoked only a small, late-onsetting effect, whereas auditory-auditory repetition evoked an effect that, at parietal sites only, was almost equivalent to that from the analogous condition of Experiment 1. These findings indicate that, as indexed by ERPs, repetition effects both within- and across-modality are influenced by lexical status. Possible parallels with the effects of word and nonword repetition on behavioral variables are discussed.

INTRODUCTION

The effects of repetition on the processing of words and other items have been the subject of intense interest for well over a decade. Initially, interest in repetition effects focused on their potential for investigating the functional architecture of the word recognition system (e.g., Clarke & Morton, 1983; Forbach, Stanners, & Hochhaus, 1974; Monsell, 1985; Morton, 1979; Murrell & Morton, 1974). More recently, repetition effects and related phenomena have also received much attention as expressions of, and as a means of studying, implicit memory (for reviews see Richardson-Klavehn & Bjork, 1988; Schacter, Chiu, & Ochsner, 1993). Theoretical issues surrounding repetition effects currently include the interrelated questions of the functional locus or loci of the effects (e.g., Rueckl, 1990), and the nature of the representations on which they operate (e.g., Brown & Carr, 1993).

One means of investigating these issues is to study the consequences of subjecting items to a transformation between their first and second presentations. If the transformation causes a reduction in the size of a repetition effect relative to that seen with direct repetition, it can be assumed that the manipulated attribute(s) form part of the representation on which repetition-sensitive processes operate. By the same logic, the absence of a transformation effect implies that the attribute affected by the transformation does not form an enduring part of the representation created or modified by the first presentation of an item.

The study of modality change on repetition effects provides one such means of investigating the representations formed or modified during item processing. Studies have consistently found that word repetition effects are diminished when repetition is across-rather than within-modality (e.g., Clarke & Morton, 1983; Jacoby & Dallas, 1981; Kirsner & Smith, 1974; Kirsner, Milech, & Standen, 1983; Monsell, 1985; Winnick & Daniel, 1970; for reviews see Kirsner, Dunn, & Standen, 1989, and Schacter et al., 1993).

As noted by Kirsner et al. (1989), word repetition effects are diminished, but not eradicated by modality change. There would appear to be (at least) two possible accounts of these modality-independent effects (see Monsell, 1985, for a more detailed exposition). They might be mediated by representations/processes operating within amodal components of the cognitive system. An obvious example would be the system subserving semantic processing. Alternatively, across-modality effects might reflect the "recoding" of an item presented in one modality into a form allowing access to the input...
system of another. An obvious example here would be the "phonological recoding" of visually presented letter strings. Both types of account have been proposed to explain across-modality word-repetition effects; Kirsner et al. (1989) suggested that the effects arose because visually and auditorily presented words converged on common "phonological output records," while Monsell (1985) argued that feedback from the speech production system to the speech input system underlay the strong visual-auditory repetition effects that he found on lexical decision times.

All of the studies of repetition effects cited above have used one or more overt measures of task performance as their dependent variable. A complementary approach is to investigate repetition effects with scalp-recorded event-related potentials (ERPs). Numerous studies have shown that ERPs are sensitive to item repetition (e.g., Bentin & Peled, 1990; Besson & Kutas, 1993; Karayanidis, Andrews, Ward, & McConaghy, 1991; Nagy & Rugg, 1989; Otten, Rugg, & Doyle, 1993; Rugg, 1985, 1987, 1990; Rugg, Furda, & Lorist, 1988; Van Petten, Kutas, Klunder, Mitchiner, & McIsaac, 1991; Young & Rugg, 1992). Several of these experiments have employed a task in which the effects of repetition are studied in the absence of overt responses to the critical items. In this task, subjects respond to occasional "target" items. The targets are interspersed among more frequently occurring "nontargets," some of which are repetitions of a preceding nontarget. The critical comparison is between the ERPs evoked by the nontargets on their second as opposed to their first presentations. When nontargets are words, and the targets are either nonwords (e.g., Rugg, 1987, 1990), or words of a designated semantic category (Rugg et al., 1988; Young & Rugg, 1992), ERPs to repeated items are more positive-going than those to first presentations. This difference—the ERP repetition effect—onsets around 250 msec poststimulus, and persists for a further 300-400 msec. It is undiminished as the lag between first and second presentations increases from zero to as many as 19 intervening items (Bentin & Peled, 1990; Nagy & Rugg, 1989; but see Karayanidis et al., 1991), but it dissipates over less than 15 min (Rugg, 1990).

The intracerebral generators responsible for the ERP repetition effect, and its functional significance, are both unknown; indeed, the latter issue is the subject of vigorous debate (cf. Rugg & Doyle, 1994; Van Petten et al., 1991). Rugg, Doyle, & Melan (1993) argued that despite the absence of such knowledge, the sensitivity of ERPs to item repetition could be exploited to shed light on how modality change influences the effects of word repetition. They pointed to two features of ERPs that made them valuable for this purpose: (1) they provide a real-time measure of processing, which permits the comparison not only of the magnitudes, but also the time courses of repetition effects; and (2) they can be recorded simultaneously from multiple scalp sites, making it possible to determine whether within- and across-modal repetitions give rise to different patterns of neural activity, and hence whether the two types of repetition are associated with different neural (and thus, most likely, functional) mechanisms.

In the study of Rugg et al. (1993), subjects monitored a sequence of randomly interleaved visual and auditory words and nonwords to detect and respond to the latter items. Some of the words were repetitions of items that had occurred six items previously, half the repeats occurring in the same modality, and half in the alternative modality. Rugg et al. found that the effects of auditory–auditory and visual–auditory repetition were indistinguishable; in both cases the repetition effect consisted of a sustained and widespread positive-going shift with an onset latency of approximately 400 msec. By contrast, visual–visual and auditory–visual repetition gave rise to different effects. In the within-modality condition, repetition effects onset approximately 200 msec poststimulus, and remained evenly distributed over the scalp for the 500 msec or so of their duration. Auditory–visual effects onset some 100-150 msec later, and exhibited a scalp distribution that became more posterior with time.

Rugg et al. (1993) proposed that their findings reflected differences in the codes formed from words presented in the two modalities (see also Monsell, 1985). They argued that phonological codes are generated from both auditorily and visually presented words. Auditory–auditory and visual–auditory conditions therefore give rise to equivalent amounts of overlap at the phonological level, and thus to equivalent ERP effects. By contrast, orthographic codes are generated only when words are presented visually. So while visual–visual repetition allows "processing overlap" at the orthographic level, auditory–visual repetition does not. For this condition, overlap is possible only at phonological or semantic levels. As it takes longer for visually presented words to generate representations at these levels than at the orthographic level, visual–visual repetition effects onset earlier than auditory–visual effects. Rugg et al. went on to argue that the representations mediating the cross-modal effects were phonological.

Rugg et al. (1993) noted that if their account of the differing effects on ERPs of visual–visual and auditory–visual repetition was correct, then the difference in onset latency between the two classes of effect could be taken as a measure of the time required to generate (or activate) phonological rather than orthographic representations of visually presented words. They acknowledged, however, that their account was predicated on the assumption that the two kinds of repetition modulated the same ERP component or components. If within-modality repetition of visually presented words causes the modulation of a component that is unaffected by across-modality repetition, then the interpretation of the different onset latencies of the two types of repetition effect is less straightforward.

The aim of the experiments reported here was to
build on the findings of Rugg et al. (1993), and to assess the validity of their account of these findings. At issue are (1) the generality of the original results to a different task, (2) whether within- and across-modality word repetitions do indeed activate a common set of ERP components, and (3) which if any of the effects described by Rugg et al. (1993) are lexically sensitive. Of these issues the first two are addressed by Experiment 1 and the third is the focus of Experiment 2.

**EXPERIMENT 1**

**Introduction**

In the study of Rugg et al. (1993), the experimental task was lexical decision. Subjects found the task quite difficult for the auditory items, missing on average approximately 20% of the auditory nonword targets, compared with only 6% of the visual targets. Because of the difficulty of the task in the auditory modality, subjects might have adopted a strategy of explicitly generating and remembering the phonological form of visually presented words, so as to aid their subsequent decision about these words should they be repeated auditorily. This strategy could have contributed to the finding of Rugg et al. of fuller across-modality repetition effects for auditorily than for visually presented words.

In light of this possibility, Experiment 1 consisted of a replication of Rugg et al. (1993) in all respects other than the task. The nonword targets of the previous study were replaced by animal names, turning the task into one of semantic discrimination. Pilot work indicated that this task was easier than lexical decision, and yielded roughly equal accuracy across the two modalities. Hence it was assumed that the task would be less likely to encourage the adoption of an explicit "phonological" strategy in the processing of the visually presented items.

**Results**

**Performance**

Accuracy was high and remarkably uniform across the two modalities. Subjects detected on average 96% of both visual (SD = 5.4) and auditory (SD = 4.0) targets. Incorrect responses were made to 2% of each of the two types of nontarget (SD visual = 2.8, SD auditory = 1.8).

Target response times (RTs) averaged 667 msec (SD = 79) for visual items and 940 msec (SD = 103) for auditory items [t(15) = 5.82, p < 0.001].

**ERPs**

Grand average ERP waveforms for first presentations, within- and across-modality repetitions, are shown for all electrode sites in Figure 1, and the corresponding subtraction waveforms are shown in Figure 2. The auditorily and visually evoked waveforms were subjected to separate analyses. In each case, analysis proceeded in three stages. First, the reliability of within- and across-modality repetition effects was assessed by ANOVA of the mean amplitude (measured with respect to the mean of the prestimulus baseline) of selected latency regions of the waveforms evoked by first presentations, within- and across-modality repetitions. To allow direct comparison with the findings of Rugg et al. (1993), the latency regions chosen for analysis corresponded to those used in that study. Separate ANOVAs were performed on data from the midline and lateral sites. When an ANOVA gave rise to a significant main effect of repetition, or to an interaction between repetition and electrode site, two further subsidiary ANOVAs, contrasting the data from each repetition condition alone with those from first presentations, were performed. In describing the outcome of these ANOVAs, effects involving the factors of electrode site and hemisphere are not reported unless they interact with the factor of condition. In these and all other ANOVAs described here, F ratios are reported with degrees of freedom adjusted by the Greenhouse-Geisser procedure to correct for nonsphericity.

More detailed analyses were conducted on repetition minus first presentation subtraction waveforms. These waveforms were analyzed by ANOVAs of successive 100 msec latency regions of the waveforms, allowing differences between the effects associated with the two repetition conditions to be directly contrasted. ANOVAs were conducted both on the raw amplitudes and after within-condition normalization across electrode sites, using the procedure recommended by McCarthy and Wood (1985). These latter analyses were conducted to determine whether the two repetition conditions yielded repetition effects that differed in scalp distribution after removal of scaling artifacts caused by differences in overall amplitude. ANOVAs of the raw amplitudes were conducted separately for midline and lateral electrodes. Those for normalized data were conducted on all nine electrode sites (factored as 3 chains [left, midline, and right] by 3 sites [frontal, central/temporal, and parietal]).

Finally, onset latencies of repetition effects were assessed for each electrode site by performing point-by-point t tests on the subtraction waveforms against the null hypothesis of no difference from baseline. As in Rugg et al. (1993), the onset latency of an effect in a given channel was defined as the latency from which at least 15 consecutive t values attained significance at the 0.05 level or better.

**Auditory ERPs.** Grand average auditory ERPs are shown in the upper half of Figure 1. Following initial N115 and P215 deflections, the waveforms are characterized by a large, sustained negative wave. The effects of repetition are seen as an attenuation of this wave. In both conditions, repetition effects onset around 400 msec poststimulus, and persist for about 600 msec. The effects are of almost equal magnitude at frontal electrodes, but in-
Initially appear larger for within- than for across-modality repetition at posterior sites.

**Raw Waveforms.** Two latency regions of these ERPs were analyzed, 400–500 msec, capturing the onset of the repetition effects evident in Figure 1, and 500–900 msec, the region in which they are of maximal amplitude. Both sets of measures are shown in Table 1. ANOVA of the 400–500 msec data from both midline and lateral sites gave rise to main effects of repetition [midline: $F(2,0,29.4) = 11.77, p < 0.001$; lateral: $F(1.8,27.6) = 9.72, p = 0.001$]. Subsidiary ANOVAs contrasting first presentations and within-modality repetition revealed significant main effects of repetition [midline: $F(1,15) = 27.40, p < 0.001$; lateral: $F(1.15) = 23.85, p < 0.001$], as did the corresponding ANOVAs for across-modality repetition [midline: $F(1,15) = 5.38, p < 0.025$; lateral: $F(1.15) = 5.46, p < 0.05$]. For the 500–900 msec latency region, the global ANOVA on midline sites gave rise to a significant effect of repetition [$F(1.9,28.5) = 37.40, p < 0.001$], and to an interaction between repetition and site [$F(2.4,35.9) = 3.37, p < 0.05$]. For the lateral sites, only the repetition effect was significant [$F(1.8,27.3) = 38.40, p < 0.001$]. Subsidiary ANOVAs contrasting first presentations and within-modality repetition gave rise, for midline sites, to significant effects for repetition [$F(1.15) = 53.51, p < 0.001$], and for the interaction of repetition and site [$F(1.3,20.1) = 5.01, p < 0.01$]. ANOVA of lateral sites revealed only a main effect of repetition [$F(1.15) = 56.45, p < 0.001$]. The repetition by site interaction for the midline data reflected a centro-parietal maximum for the repetition effects in this latency region. The second pair of ANOVAs, comparing first presentations and across-modality repetition, gave rise in each case only to main effects of repetition [midline: $F(1,15) = 55.16, p < 0.001$; lateral: $F(1,15) = 41.25, p < 0.001$].

**Subtraction Waveforms.** ANOVA of the raw amplitudes of consecutive 100 msec latency regions of the subtraction waveforms revealed significant effects of repetition condition for the 500–600 msec region [midline: $F(1,15) = 9.49, p < 0.01$; lateral: $F(1,15) = 11.75, p < 0.005$], signifying larger within- than across-modality effects. Significant effects of condition were also found for the succeeding latency region [midline: $F(1,15) = 5.73, p < 0.05$; lateral: $F(1,15) = 6.52, p < 0.05$].
Figure 2. Grand-average auditory (upper) and visual (lower) subtraction waveforms from Experiment 1, obtained by subtracting ERPs to first presentations from those evoked by within- and across-modality repetitions. Electrode sites as in Figure 1.

Table 1. Mean Amplitude of the 400-500 and 500-900 msec Latency Regions of Auditory ERPs in Experiment 1

<table>
<thead>
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<th>Fz</th>
<th>Cz</th>
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<th>LP</th>
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<tr>
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<td>-7.7</td>
<td>-5.2</td>
<td>-5.8</td>
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<td>-3.1</td>
<td>-5.8</td>
<td>-5.2</td>
<td>-3.9</td>
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<tr>
<td>Within</td>
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<td>-4.3</td>
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<td>-1.6</td>
<td>-4.2</td>
<td>-3.4</td>
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<tr>
<td>Across</td>
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<td>-4.0</td>
<td>-4.5</td>
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<td>-2.4</td>
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<td>500-900</td>
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<tr>
<td>First</td>
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<td>-6.9</td>
<td>-3.5</td>
<td>-7.8</td>
<td>-5.6</td>
<td>-1.5</td>
<td>-7.9</td>
<td>-6.1</td>
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<tr>
<td>Within</td>
<td>-5.3</td>
<td>-2.0</td>
<td>1.5</td>
<td>-5.1</td>
<td>-1.8</td>
<td>1.4</td>
<td>-5.2</td>
<td>-1.9</td>
<td>1.4</td>
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<tr>
<td>Across</td>
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<td>-2.5</td>
<td>0.0</td>
<td>-4.8</td>
<td>-2.2</td>
<td>1.1</td>
<td>-5.4</td>
<td>-2.9</td>
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along with condition by site interactions [midline: $F(1.2,17.5) = 4.51, p < 0.05$; lateral: $F(1.1,16.1) = 6.10, p < 0.025$]. These effects reflected larger differences between conditions at parietal than at frontal electrodes. Finally, the 900-1000 and 1000-1100 msec latency regions each revealed a significant three-way interaction between condition, hemisphere, and site [900-1000: $F(1.3,20.1) = 7.91, p < 0.01$; 1000-1100: $F(1.4,21.5) = 5.45, p < 0.025$]. These interactions reflected the fact that in the within-modality condition only, the repetition effects were larger at right than left parietal electrodes.

Topographic Analyses. ANOVAs of normalized amplitudes revealed only two interactions involving repetition condition. In the 600-700 msec latency region there was a significant interaction between condition and site.
anterior-posterior distributions for the two kinds of repetition (centroparietal for within, and frontocentral for across). And for the 900-1000 msec region, there was a marginally significant three-way interaction between condition, electrode chain, and site \(F(3.3,49.9) = 2.71, p = 0.05\), reflecting the asymmetric distribution of voltage in favor of the left parietal electrode in the within-modality condition.

Onset Latencies. Point-by-point t tests indicated that the within-modality effect first onset at the right temporal electrode at 408 msec. The equivalent value for the Cz site was 420 msec. Across-modality effects first onset at a latency of 444 msec at the Cz electrode.

Visual ERPs. ERPs evoked by visually presented words are shown in the lower half of Figure 1. N85 and P170 deflections are followed by broader negative (N400) and positive (P600) waves. Within-modality repetition begins to exert an effect from around 200 msec poststimulus, taking the form of the attenuation of the N400, and the enhancement of the subsequent P600. By contrast, across-modality repetition effects onset some 200 msec later, and appear to involve modulation of the waveform solely in the region of P600. The effect on this deflection appears to be larger and more sustained than that seen in the within-modality condition.

Raw Waveforms. ANOVAs were conducted on the mean amplitudes of the 200–400, 400–600, and 600–800 msec latency regions, the data for which are shown in Table 2. ANOVA of the 200–400 msec region revealed significant effects for repetition \(F(1,15) = 11.06, p < 0.001\); lateral: \(F(1,15) = 10.68, p < 0.001\). The subsidiary ANOVAs contrasting within-modality repetition and first presentations also indicated significant repetition effects \(F(1,15) = 21.97, p < 0.001\); lateral: \(F(1,15) = 19.82, p < 0.001\). The equivalent ANOVAs for the across-modality condition yielded no significant effects. ANOVAs of the 400–600 msec latency region revealed significant effects for repetition \(F(1,15) = 12.61, p < 0.001\); lateral: \(F(1,15) = 12.85, p < 0.001\), and significant interactions between repetition and site \(F(2.4,35.5) = 5.41, p < 0.01\); lateral: \(F(2.3,35.1) = 4.00, p < 0.025\). The follow-up ANOVAs for within-modality repetition gave rise to the same two effects at midline sites \(F(1,15) = 31.43, p < 0.001\); repetition by site: \(F(1,15) = 4.82, p < 0.05\), reflecting the centroparietal maximum of these effects on the midline in this latency region. ANOVA of the lateral sites gave rise solely to a main effect of repetition \(F(1,15) = 37.34, p < 0.001\). ANOVAs for the across-modality condition gave similar results, except that for both midline and lateral sites the effect of repetition was accompanied by a repetition by site interaction \(F(1,15) = 10.48, p < 0.01\), and \(F(1,15) = 8.86, p < 0.001\), respectively; lateral: \(F(1,15) = 6.40, p < 0.025\), and \(F(1,15) = 7.25, p < 0.01\). These results reflect the strong anterior-posterior gradient (parietal maximum) in the size of the across-modality effects in this latency range.

The global ANOVA for the 600–800 msec latency range once more revealed significant effects for repetition and its interaction with site \(F(1,15) = 6.20, p < 0.01\), and \(F(2,23.7) = 7.61, p = 0.001\), respectively; lateral: \(F(2,29.4) = 8.48, p = 0.001\), and \(F(2.6,38.6) = 8.98, p < 0.001\), respectively. In the follow-up ANOVAs for the within-modality condition, those for midline sites gave rise to no significant effects, whereas for lateral sites a main effect of repetition was found \(F(1,15) = 7.63, p < 0.025\). Both ANOVAs of the across-

| Table 2. Mean Amplitude of the 200–400, 400–600, and 600–800 msec Latency Regions of Visual ERPs in Experiment 1 |
|-----------------|-----------------|-----------------|-----------------|-----------------|-------|-------|-------|-------|
|                 | Pz  | Cz  | Pz  | LF  | LT  | LP  | RF  | RT  | RP  |
| 200–400         |     |     |     |     |     |     |     |     |     |
| First           | 1.9 | 2.7 | 5.3 | 1.8 | 1.9 | 2.6 | 2.6 | 2.3 | 3.5 |
| Within          | 3.8 | 4.9 | 7.1 | 3.4 | 3.5 | 3.8 | 3.9 | 3.6 | 5.0 |
| Across          | 2.5 | 3.6 | 6.3 | 2.0 | 2.1 | 3.0 | 3.1 | 2.8 | 4.3 |
| 400–600         |     |     |     |     |     |     |     |     |     |
| First           | 1.3 | 3.0 | 4.6 | 1.1 | 2.7 | 0.9 | 1.3 | 1.9 | 1.0 |
| Within          | 3.5 | 6.5 | 7.8 | 2.9 | 5.0 | 3.2 | 3.0 | 4.5 | 4.0 |
| Across          | 2.1 | 5.2 | 7.5 | 1.3 | 3.5 | 2.8 | 1.9 | 3.3 | 3.4 |
| 600–800         |     |     |     |     |     |     |     |     |     |
| First           | 1.5 | 4.9 | 5.0 | 1.4 | 4.2 | 1.9 | 2.3 | 4.1 | 2.2 |
| Within          | 2.1 | 6.0 | 6.4 | 2.5 | 5.0 | 2.9 | 3.6 | 5.7 | 4.1 |
| Across          | 2.1 | 7.3 | 8.7 | 1.6 | 5.7 | 4.8 | 3.3 | 6.6 | 5.9 |
modality condition revealed main effects for repetition [midline: $F(1,15) = 13.72, p < 0.005$; lateral: $F(1,15) = 17.01, p = 0.001$] and for its interaction with site [midline: $F(1.4,20.4) = 14.41, p < 0.001$; lateral: $F(1.4,21.0) = 13.34, p = 0.001$], reflecting the posterior maximum of these repetition effects. In addition, the ANOVA of the lateral sites for the across-modality condition revealed a significant interaction between repetition and hemisphere [$F(1,15) = 4.66, p < 0.05$], reflecting larger repetition effects over the right hemisphere.

**Subtraction Waveforms.** ANOVA of successive 100 msec latency regions of the subtraction waveforms shown in the lower part of Figure 2 revealed main effects of repetition condition for the 300-400 msec [midline: $F(1,15) = 12.70, p < 0.005$; lateral: $F(1,15) = 13.98, p < 0.005$] and 400-500 msec [midline: $F(1,15) = 12.40, p < 0.005$; lateral: $F(1,15) = 15.53, p = 0.001$] latency regions. These results reflected larger within- than across-modality repetition effects. ANOVA of the 500-600 msec region gave rise to no significant effect, as was true also for the analysis of the midline data for the 600-700 msec region. However, ANOVA of the 600-700 msec data from the lateral sites revealed a significant interaction between condition and site [$F(1.3,19.3) = 5.39, p < 0.025$]. This reflected larger across- than within-modality effects at the parietal sites. Condition by site interactions were found also for the 700-800 and 800-900 msec intervals [midline: $F(1.4,21.0) = 10.10, p < 0.005, f(1.2,18.5) = 6.79, p < 0.025$, respectively; lateral: $F(1.4,20.6) = 16.58, p < 0.001, F(1.3,19.1) = 7.18, p < 0.025$, respectively]. These too reflected larger across- than within-modality effects.

**Topographic Analyses.** ANOVAs of rescaled data gave rise to no significant interactions between condition and any topographic variable in the intervals between 200-300 and 900-1000 msec. Further analyses were conducted to directly address the question, central to the aim of the experiment, of whether the early modality dependent repetition effect differed in its topography from the later, across-modality effect. These analyses compared the scalp distribution of the 300-400 msec region of the within-modality subtraction waveforms with the distribution of the 700-800 msec region of the across-modality waveforms. ANOVA gave rise to a significant interaction between repetition condition and electrode chain [$F(1.6,24.7) = 8.65, p < 0.005$], and to a marginally significant interaction between condition and electrode site [$F(1.3,19.4) = 3.88, p = 0.054$]. The first of these effects reflected the relatively greater amplitude over the right hemisphere for the across- compared to the within-modality effect, as illustrated in Figure 3. Separate ANOVAs of the data from each electrode chain revealed a significant condition by site interaction for the left hemisphere electrode sites [$F(1.3,19.5) = 5.07, p < 0.05$], and a marginally significant interaction for the midline electrodes [$F(1.3,19.4) = 3.82, p = 0.056$]. As can be seen from Figure 3, these effects reflect the differing anterior-posterior gradients associated with the two repetition conditions, the within-modality effect showing the more posterior distribution.

**Onset Latencies.** Serial $t$ tests indicated that the earliest onset of the within-modality effects was at 240 msec at the left frontal electrode. The onset of these effects at the Cz electrode was 264 msec. The across-modality effects first onset at the right parietal electrode at 426 msec, and at Cz at 534 msec.

**Summary**

Auditory-auditory and visual-auditory repetition gave rise to repetition effects with very similar onset latencies and, at anterior sites, magnitudes. At posterior electrodes, however, the effects of auditory-auditory repetition were initially larger than those evoked by repetition across-modality. ERPs evoked by visually presented words differed markedly according to whether repetition was within- or across-modality. Visual-visual repetition evoked an effect that onset early, and that changed its scalp distribution over time from equipotential over the midline to posterior-maximum. The effects of auditory-visual repetition onset some 200 msec later, maintained a consistent posterior maximum over time, and exceeded and outlasted the within-modality effects.
Discussion

The goal of this experiment was to assess the generality of the findings of Rugg et al. (1993) and, in particular, to compare the effects of within- and across-modality word repetition in a task of roughly equal difficulty in the two modalities. Consistent with this goal, the semantic detection task used here gave rise to high and equally accurate levels of performance in the two modalities.

The data from the auditory modality differ in two ways from those of Rugg et al. (1993). Whereas in the previous study auditory-auditory and visual-auditory repetition gave rise to indistinguishable effects, here the within-modality effects were initially larger in magnitude, especially at posterior electrode sites. Also in contrast to the previous study, the two types of repetition effect show some evidence of differing in scalp topography, the within-modality effect exhibiting the more posterior and asymmetric distribution.

Thus it is possible that the within- vs. across-modality manipulation dissociated two spatially and temporally overlapping repetition-sensitive auditory ERP components. One, with a relatively uniform scalp distribution, is modulated equally by both types of repetition. The second component, with a strongly posterior distribution and of shorter duration, is modulated more by within-modality repetition.

Why should the present data differ from those of Rugg et al. (1993)? A likely explanation is that, for the reasons outlined in the Introduction, subjects adopted a more explicitly "phonological" strategy in the previous study than in this one. Such a strategy may have potentiated the formation of phonological codes from visual items, and hence contributed to a higher degree of processing overlap between visual and auditory words than in the present experiment (see Monsell, 1985, and McClelland & Pring, 1991, for evidence that visual-auditory word repetition effects on performance covary with the amount of phonological processing accorded visual items).

The repetition effects on the ERPs evoked by visually presented words demonstrate an even more striking dissociation between the effects of within- and across-modality repetition than that described by Rugg et al. (1993). The visual–visual effects onset early, and resulted from the modulation of two topographically distinct components. Auditory–visual effects onset some 200 msec later, and appear to involve only the second of these components. As in the previous study, the effects of across-modality repetition on this later, posterior-maximum component outlasted the within-modality effects.

These results seem to resolve the ambiguity left by the findings of Rugg et al. (1993), in that they show that visual–visual and auditory–visual repetition effects are indeed associated with the modulation of distinct components. Thus differences between the onset latencies of these effects cannot be taken to reflect differences in the onset of a common set of neural processes. It would appear instead that lagged visual–visual repetition initially modulates a modality-dependent ERP component.

These findings weaken the hypothesis of Rugg et al. that the different onset latencies of visual–visual and auditory–visual ERP repetition effects provide a direct measure of the additional time required to generate phonological rather than orthographic codes from visually presented words. The hypothesis remains valid only on the strong assumption that the same temporal relationship exists between each ERP effect and the processing to which it is sensitive. However, this does not invalidate the argument of Rugg et al. that the within- and across-modality repetition effects reflect processing overlap in different processing domains (orthographic and phonological, respectively). Nor does it negate the possibility that differences in the time taken to generate representations in these two domains contribute to the differing time courses of the two effects.

Although within- and across-modality repetition effects on the auditory ERPs differed more than in the study of Rugg et al. (1993), the present and previous findings are in broad agreement in one important respect. Once again, across-modality effects more closely resembled within-modality effects when repetition was visual–auditory than vice versa. Hence the results again echo Monsell’s (1985) finding of fuller across-modality effects on lexical decision performance in the visual–auditory direction.

Also as reported by Rugg et al. (1993), the across-modality repetition effect for visually presented words outlasted the within-modality effect, especially at parietal sites. It is unclear how this difference should be interpreted. It could be a consequence of the fact that the component in question onset later when evoked by across-modality repetition, in which case the difference could simply reflect a corresponding delay in offset latency. Alternatively, it may reflect a true difference in the amplitude and duration of the effects of the two types of repetition. Since in the present study (but not in Rugg et al., 1993) the peak amplitude of the across-modality effect reliably exceeded that of the within-modality effect, the latter of these alternatives seems the more likely. If so, these data suggest that some repetition-sensitive processes may be activated to a greater extent, or for a longer duration, by repetition across- rather than within-modality.

An important question raised by the present and past studies of across-modality ERP repetition effects concerns the nature of the codes/representations mediating the effects. The lack of symmetry in the pattern of across-modality effects is inconsistent with the idea that the effects are mediated solely by processing at a single, amodal locus such as the semantic system. The data do not, however, place very strong constraints on the range of other loci at which across-modality effects might operate. The aim of Experiment 2 was to strengthen these
constraints by investigating the effects on ERPs of the repetition of pronounceable nonwords.

**EXPERIMENT 2**

**Introduction**

Nonwords have no preexisting lexical or semantic representation. The investigation of nonword repetition thus offers a way to determine the role played in word repetition effects by processing at lexical and semantic levels. This is not to deny the possibility that nonwords to some extent engage processes at those levels; indeed, according to some accounts of word recognition, such as the interactive activation model of McClelland and Rumelhart (1981; Rumelhart & McClelland, 1982), nonwords that closely resemble words partially activate the lexical representations corresponding to those words. Thus the mere fact that nonword repetition effects can be shown to exist is not sufficient in itself to rule out lexical (or, conceivably, semantic) contributions to such effects [see Bowers (1994) for a discussion of this issue]. Nonetheless, when word and nonword repetition effects differ in tasks that are otherwise comparable, it seems reasonable to suppose that the effects are sensitive to lexical or semantic processing, since it is processing at these levels that differentiates the two classes of item.

Two previous studies of ERP repetition effects for visually presented nonwords have been reported, both of which studied the effects of immediate repetition only. Rugg (1987) found that repeated nonwords evoked an effect qualitatively similar to that seen with words, but with a somewhat delayed onset and diminished amplitude. He suggested that even at zero lag, lexical factors play a role in the mediation of ERP repetition effects.

Rugg and Nagy (1987) compared the effects of repeating orthographically legal (e.g., FLEEBO) and illegal (e.g., SKHRA) nonwords. They found that legal items gave rise to large and robust effects, whereas illegal items evoked little or no effect. Rugg and Nagy argued that in contrast to the illegal nonwords, the orthographic attributes of legal nonwords allowed such items to gain access to the lexical system. They suggested that their findings pointed to a critical role for sublexical or even lexical processing in the mediation of nonword repetition effects. Rugg and Doyle (1994) noted, however, that although Rugg and Nagy’s findings were incompatible with a purely episodic account of ERP repetition effects, they did not necessarily point to a role for lexical processing. Legal and illegal nonwords differ not only in how word-like they are, but also in whether they are pronounceable. Thus Rugg and Nagy’s (1987) findings could indicate that ERP repetition effects are dependent on whether items can easily be encoded phonologically, rather than whether they are processed lexically.

Behavioral studies of nonword repetition effects have led to inconsistent findings. For the lexical decision task, nonword effects have in the main been reported only with very short inter item lags (e.g., Bentin & Moscovitch, 1988; Dannenbring & Briand, 1982; Forbach et al., 1974; Scarborough, Cortese, & Scarborough, 1977; Monsell, 1985). These findings have led to the view (Monsell, 1985) that long-term word repetition effects are lexically mediated, and receive little or no contribution from either sublexical processes or episodic memory. However, in tasks requiring the identification of degraded stimuli, robust, persistent nonword repetition effects have consistently been reported (e.g., Bowers, 1994; Feustel, Shiffrin, & Salasoo, 1983; Haist, Musen, & Squire, 1991; Rueckl, 1990; Rueckl & Olds, 1993; Salasoo, Shiffrin, & Feustel, 1985; Whitlow, 1990). These findings have led to the view that word and nonword repetition effects share at least one common mechanism. By one argument, this mechanism involves the (implicit) retrieval of the prior processing episode involving the item (e.g., Jacoby, 1983; Feustel et al., 1983). Alternatively, it has been proposed that the processes common to word and nonword repetition effects are located within the visual word-form system—a domain-specific system subserving the processing of orthography (e.g., Schacter et al., 1993). It has also been suggested that repetition effects are mediated by the combination of two mechanisms: episodic retrieval, equally available for words and nonwords, and activation within lexical memory, a mechanism largely specific to words (Whitlow, 1990; but see Rueckl & Olds, 1993).

The reasons for the inconsistent findings between lexical decision and identification tasks are unclear. It has been argued that the difficulty in demonstrating long-term nonword repetition effects on lexical decision performance stems from a peculiarity of the task. By this argument (e.g., Bowers, 1994; Feustel et al., 1983), the gain in familiarity of nonwords when they are repeated impedes their rejection as words, and offsets any benefit to earlier stages of their processing. Alternatively, the inconsistent findings may indicate that repetition effects in perceptual identification and lexical decision tasks have different functional loci. Identification tasks are heavily data-limited, and may, therefore, be especially sensitive to changes in the efficiency of relatively early perceptual processes, which are modified equally by the repetition of words and nonwords. By contrast, lexical decision tasks may be more dependent on processes subserving, or consequential on, access to lexical or semantic representations (Keane, Gabrieli, Fennema, Growdon, & Corkin, 1991; Weldon, 1993).

In view of these issues, Experiment 2 is of interest for reasons other than the light it might shed on cross-modality word repetition effects on ERPs. It affords the opportunity to compare the effects of nonword repetition on ERPs with those evoked by word repetition under similar circumstances. If word and nonword effects do not differ, or differ only quantitatively, this would support the view that the two types of effect share a
common mechanism. On the other hand, a qualitative difference between the two effects would lend support to the view that the differing longevities of word and nonword repetition effects in the lexical decision task reflect functionally significant differences in the way repeated words and nonwords are processed.

To address these issues, Experiment 2 investigated the consequences of the within- and across-modality repetition of nonwords in a target detection task analogous to that employed by Rugg et al. (1993). In the present task, auditorily presented targets were words, while visually presented targets were pseudohomophonic nonwords (e.g., PHOCKS). By employing these latter items as targets we hoped to ensure that the visually presented nonwords were uniformly subjected to phonological recoding. Hence weak or absent repetition effects with these items cannot be attributed to a failure to generate phonological representations from them.³

Results

Performance

Subjects detected an average of 67% (SD = 9.9) of the visual targets and 85% (SD = 5.4) of the auditory targets. Responses were correctly withheld on 96% (SD = 2.1) of visual, and 94% (SD = 2.3) of auditory nontarget trials. ANOVA of these data gave rise to main effects of response type and modality [F(1,15) = 151.30, p < 0.001, and F(1,15) = 41.24, p < 0.001, respectively], and to a significant interaction between these factors [F(1,15) = 83.51, p < 0.001]. Post hoc Tukey tests showed that subjects detected fewer visual than auditory targets, and that for both modalities, correct detections were less frequent than correct rejections. Target RTs averaged 991 msec (SD = 111) for visual items, and 1179 msec (SD = 90.4) for auditory items [t(15) = 6.88, p < 0.001].

ERPs

Grand average waveforms for first presentations, within- and across-modality repetitions are shown in Figure 4, and the corresponding subtraction waveforms are shown in Figure 5. The analysis strategy for these data was identical to that in Experiment 1, with the exception of some adjustments to the latency regions selected for analysis, to take account of differences between experiments in the timing and duration of the repetition effects.

Figure 4. Grand-average auditory (upper) and visual (lower) ERPs from Experiment 2 evoked by first presentations, within- and across-modality repetitions. Electrode sites as in Figure 1.
**Figure 5.** Grand-average auditory (upper) and visual (lower) subtraction waveforms from Experiment 2. Electrode sites as in Figure 1.

*Auditory ERPs.* As shown in the upper part of Figure 4, the general morphology of these ERPs closely resembles that seen in Experiment 1, although the effects of repetition appear to differ. Repetition within-modality is associated with a large positive-going shift in the waveform, onsetting at parietal sites around 400 msec. The magnitude of this effect is greatly diminished, and its onset latency lengthened, at anterior sites. Across-modality repetition evokes a much smaller effect, which onsets some 200-300 msec later than the within-modality effect.

*Raw Waveforms.* Two latency regions, 400-600 msec and 600-1000 msec, were subject to ANOVA (Table 3 shows the mean values of these measures). These regions encompass intervals when the waveforms appear to be modulated solely by repetition within modality, and when both repetition conditions evoked an effect. ANOVA of the 400-600 msec measures gave rise for both midline and lateral data to a significant repetition by site interaction [midline: F(2.5,37.8) = 4.35, p < 0.025; lateral: F(2.3,33.9) = 3.50, p < 0.05]. Subsidiary ANOVAs for the within-modality data revealed a main effect of repetition for the midline data [F(1,15) = 5.99, p < 0.05], and repetition by site interactions for both midline and lateral measures [midline: F(1.7,26.1) = 8.82, p < 0.005; lateral: F(1.5,23.0) = 8.01, p < 0.005]. These interactions reflect the very marked parietal maximum of the within-modality repetition effect during this interval. The ANOVAs contrasting across-modality repetition with first presentations gave rise to no significant effects.

Global ANOVAs of the 600-1000 msec interval gave rise to significant main effects of repetition [midline: F(1.9,28.8) = 12.09, p < 0.001; lateral: F(1.9,29.1) = 11.60, p < 0.001], and to an interaction between repetition and electrode site [midline: F(2.5,36.8) = 8.45, p < 0.001; lateral: F(2.3,34.6) = 5.25, p < 0.01]. ANOVA of the within-modality condition revealed the same two effects for both midline [F(1,15) = 23.53, p < 0.001; F(1.5,22.7) = 22.00, p < 0.001] and lateral [F(1,15) = 25.92, p < 0.001; F(1.8,27.5) = 13.68, p < 0.001] data, indicating that these repetition effects maintained their parietal maximum in this later interval. By contrast, ANOVA of the between-modality data revealed sig-
significant effects of repetition [midline: \(F(1,15) = 6.97, p < 0.025\); lateral: \(F(1,15) = 6.23, p = 0.025\)], but no interaction with site.

**Subtraction Waveforms.** ANOVAs contrasting successive 100 msec intervals of the subtraction waveforms showed significant effects between 500-600 and 900-1000 msec. On the midline, condition by site interactions were found for all the intervals noted above [500-600: \(F(1.4,20.5) = 4.42, p < 0.05\); 600-700: \(F(1.4,20.3) = 3.96, p = 0.05\); 700-800: \(F(1.4,21.4) = 7.75, p < 0.01\); 800-900: \(F(1.6,23.3) = 3.70, p = 0.05\); 900-1000: \(F(1.4,21.5) = 6.04, p < 0.025\)]. In each case the interaction reflected the parietal distribution of the difference between the two repetition conditions. ANOVA of the 600-700 msec data from the midline also revealed a condition main effect \([F(1,15) = 5.44, p < 0.05]\). For lateral sites, condition by site interactions were found for the 600-700 msec and 700-800 msec intervals only \([F(1.4,21.0) = 4.25, p < 0.05]; F(1.4,21.5) = 4.94, p < 0.05]\), while ANOVA of the 800-900 msec region gave rise to a condition main effect \([F(1,15) = 7.22, p < 0.025]\). ANOVA of the mean amplitudes of the same latency regions after rescaling revealed no effects involving the factor of condition.

**Onset Latencies.** Serial \(t\) tests showed that the within-modality effects first onset at the left parietal electrode at 390 msec poststimulus. Across-modality effects also first onset at the left parietal electrode, but at a latency of 690 msec. Onset of the within- and across-modality effects at \(C_2\) were 564 and 714 msec, respectively. The 300 msec difference between the two conditions in onset latencies at the left parietal electrode was not mirrored at anterior sites. At the \(F_2\) electrode, for example, the onset latencies of the two repetition effects were identical, at 774 msec.

**Visual ERPs.** As was true for the auditory ERPs, the visual ERPs (lower half of Fig. 4) are morphologically similar to those recorded in Experiment 1. The within-modality effects of repetition differ from those in the previous experiment however, in that they do not onset

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**Table 3. Mean Amplitude of the 400-600 and 600-1000 msec Latency Regions of Auditory ERPs in Experiment 2**

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<th>(F_2)</th>
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<th>(L_P)</th>
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<td>-4.8</td>
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**Table 4. Mean Amplitude of the 200-400, 400-600, and 600-800 msec Latency Regions of Visual ERPs in Experiment 2**

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<tr>
<td><strong>First</strong></td>
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<tr>
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until around 400 msec. Across-modality effects show a more posteriorly distributed and somewhat delayed pattern.

**Raw Waveforms.** As in Experiment 1, global ANOVAs were conducted on the mean amplitudes of three successive 200 msec latency regions: 200–400, 400–600, and 600–800 msec, respectively, the mean values of which are shown in Table 4. ANOVAs of the first of these regions revealed no significant effects. ANOVAs of the 400–600 msec region gave rise to significant main effects of repetition [midline: \(F(1.5,21.9) = 7.26, p < 0.01\); lateral: \(F(1.4,21.4) = 4.17, p < 0.05\)]. Follow-up ANOVAs on the within-modality data gave rise in the case of the midline electrodes to effects for repetition \([F(1,15) = 9.04, p < 0.01]\), and for the interaction between repetition and site \([F(1.2,18.1) = 5.14, p < 0.05]\). ANOVA of the lateral data gave rise solely to a main effect of repetition \([F(1,15) = 5.36, p < 0.05]\). Subsidiary ANOVAs on the across-modality data revealed no significant effects on the midline, but a reliable repetition effect for data from the lateral electrodes \([F(1,15) = 4.80, p < 0.05]\).

For the 600–800 msec region, the global ANOVA revealed repetition effects and repetition by site interactions for both midline \([F(1.6,24.2) = 8.04, p < 0.005\); \(F(2.6,38.3) = 4.70, p = 0.01\)] and lateral sites \([F(1.5,23.1) = 7.77, p = 0.005\); \(F(2.6,38.6) = 4.20, p < 0.025\)]. ANOVA of the midline data for the within-modality condition revealed only a main effect of repetition \([F(1,15) = 8.41, p < 0.025]\). ANOVA of the lateral data from this condition gave rise once again to an effect of repetition \([F(1,15) = 8.12, p < 0.025]\), and also to a reliable three-way interaction between repetition, hemisphere, and site \([F(1.9,29.2) = 3.46, p < 0.05]\). This interaction reflected the tendency for the small asymmetry in the size of these effects favoring the left frontal and temporal electrodes to reverse at the parietal sites. Subsidiary ANOVAs on the 600–800 msec interval for across-modality repetition gave rise to a reliable repetition effect, and to an interaction between repetition and electrode site, in both midline \([F(1,15) = 17.72, p = 0.001\); \(F(1.4,20.5) = 9.03, p < 0.005\)] and lateral \([F(1,15) = 18.81, p = 0.001\); \(F(1.5,22.6) = 6.70, p < 0.01\)] data. These results reflect the robust across-modality repetition effects in this latency range, and their marked centroparietal distribution.

**Subtraction Waveforms.** Analyses contrasting successive 100 msec latency regions of the subtraction waveforms gave rise to significant effects for all intervals between 400–500 and 800–900 msec. For midline sites, these took the form of significant condition effects for the regions 400–500 and 500–600 msec \([400–500: F(1,15) = 4.66, p < 0.05; 500–600: F(1,15) = 6.85, p < 0.025]\), and to significant interactions between condition and site for the 600–700 and 700–800 msec regions \([600–700: F(1.5,23.1) = 4.73, p < 0.05; 700–800: F(1.3,19.4) = 4.36, p < 0.05]\). The outcome of the first two ANOVAs reflects the larger within- than across-modality effects in these latency regions. In the case of the 600–700 msec region, the condition by site interaction again reflects larger effects for the within-modality condition, but this difference is now largely confined to the frontal electrode. The same interaction in the 700–800 msec data reflects larger across- than within-modality effects, but only at the parietal electrode.

ANOVAs of the subtraction waveforms from the lateral sites gave rise to significant condition by site interactions for 600–700, 700–800, and 800–900 msec latency regions \([600–700: F(1.5,23.2) = 5.00, p < 0.025; 700–800: F(1.4,20.5) = 5.21, p < 0.025; 800–900: F(1.3,19.9) = 4.72, p < 0.05]\). For the first of these ANOVAs, this interaction reflected larger within- than across-modality effects, a difference largely confined to the frontal electrodes. For the latter two latency regions, the interactions arose because of a reversal of this difference at temporal and parietal electrodes. The condition by site interactions found for the ANOVAs of the 600–700 and 700–800 msec regions were modified by a three-way interaction between these factors and hemisphere \([600–700: F(1.9,28.5) = 4.04, p < 0.05; 700–800: F(1.8,26.3) = 3.76, p < 0.05]\). These interactions are elucidated below.

**Topographic Analyses.** ANOVAs of the rescaled data for the 600–700, 700–800, and 800–900 msec latency regions revealed in each case significant interactions between condition, electrode chain, and site \([600–700: F(3.4,51.0) = 3.19, p < 0.05; 700–800: F(3.1,46.7) = 3.45, p < 0.025; 800–900: F(3.3,49.2) = 4.40, p < 0.01]\). These interactions were clarified by performing subsidiary ANOVAs on the data from the midline and lateral sites. For each latency region, ANOVA of the lateral data showed a reliable three-way interaction between hemisphere, site, and condition. These interactions reflected different patterns of asymmetry in the two sets of subtraction waveforms. For both within- and across-modality conditions, repetition effects are larger over the left than the right frontal and temporal electrodes. The same trend is true also at the parietal electrodes for the across-modality condition, but is reversed at these sites in the within-modality condition. For the 600–700 msec region only, subsidiary ANOVAs also revealed an additional and important effect: at left hemisphere and midline electrodes a site by condition interaction was found, reflecting a more frontal distribution for the within- than the across-modality repetition effects.

**Onset Latencies.** Serial t tests showed that the earliest onset latency for the within-modality effects was 444 msec, at the Cz electrode. Across-modality effects first onset at the right temporal electrode at 498 msec, onset at Cz at 504 msec.
**Summary**

Auditory-auditory repetition gave rise to a large, sharply posteriorly distributed effect that onsets at a similar latency to the auditory-auditory effect in Experiment 1. By contrast, the effect of visual-auditory repetition was small, equipotential over the midline, and onset some 300 msec later than the within-modality effect. Visual-auditory repetition effects onset approximately 50 msec earlier than those evoked by auditory-auditory repetition, and were more anteriorly distributed. As in Experiment 1, auditory-visual effects outlasted the effects of within modality repetition.

**Discussion**

These findings provide a striking contrast to those of Experiment 1 and Rugg et al. (1993). ERP repetition effects again fractionated according to whether repetition was within- or across-modality, but in a manner quite different from that seen previously.

At parietal electrodes, the within-modality effects on auditory ERPs were comparable to those found with words in Experiment 1, with respect to both amplitude and onset latency. But while in that experiment the difference between Fz and Pz in the onset of the auditory-auditory effects was a mere 12 msec, here it was 300 msec. One explanation for this difference is that in the present experiment, within-modality repetition initially modulated only one of the two components hypothesized to underlie the auditory repetition effects observed in Experiment 1. By this account, the parietally distributed difference between within- and across-modality repetition in Experiment 1, and the early within-modality effect in Experiment 2, each reflects the modulation of the same modality-dependent component.

In contrast to Experiment 1, visual-auditory repetition effects were markedly delayed in onset relative to the within-modality condition and, for much of their duration, were smaller in magnitude, especially at parietal sites. Thus it can be concluded that visual-auditory ERP repetition effects are lexically sensitive.

In combination with the results of Experiment 1, the present data also point to a role for lexical factors in the ERP repetition effects evoked by visually presented items, in that the nonword visual-auditory repetition effects onset some 200 msec later than the equivalent effects with words. As in Experiment 1, however, these effects onset earlier than the across-modality effects and displayed a more anterior scalp distribution. This latter finding indicates that visual-auditory and auditory-auditory repetition of nonwords engage dissociable neural, and hence most likely cognitive, processes.

Again as in Experiment 1, auditory-visual repetition gave rise to a more sustained effect than visual-visual repetition did, especially at parietal electrodes. Therefore whatever the processes reflected by this difference between within- and across-modality repetition, they are not lexically specific. Unlike in Experiment 1, the difference was asymmetric, in that it was absent at the right parietal site. This suggests that the generators in each hemisphere responsible for the "late" repetition effect on visual ERPs can, in certain circumstances, become uncoupled. It is, however, not possible to suggest a functional account of these findings. The interpretation of lateral asymmetries in ERPs is fraught with difficulty (Rugg, Kok, Barrett, & Fischler, 1986), and other evidence about the relative contributions of each hemisphere to word and nonword repetition effects is extremely limited (but see Marsolek, Kosslyn, & Squire, 1992).

**GENERAL DISCUSSION**

The findings from the two experiments will first be discussed with respect to their relevance for general issues surrounding the effects of word and nonword repetition. Subsequently, their relevance to the question of the nature of the processing and representations reflected by the ERP repetition effect will be considered.

**Word and Nonword Repetition Effects**

The findings from these experiments lend strong support to the view (Monsell, 1985; Rugg et al., 1993) that the transfer of word repetition effects between modalities is stronger in the visual-auditory direction than vice versa. Furthermore, the findings from Experiment 2 suggest that auditory-visual transfer depends heavily on lexical processing.

In both modalities, evidence was found for early-acting repetition-sensitive processes specific to words. The absence of such early repetition effects for nonwords, especially evident in the visual-auditory condition, suggests that word and nonword repetitions do indeed have different processing consequences; at the very least, the two classes of item engage repetition-sensitive processes that differ in their time courses. Hence the insensitivity of the lexical decision task to lagged nonword repetition may well reflect more than just the opposing influences of speeded identification and slowed response selection (Feustel et al., 1983; Bowers, 1994).

Repetition effects on behavior would be expected to reflect not only the amount of processing overlap between first and second encounters with an item, but also the time at which such overlap begins relative to the moment of response selection. The present findings, along with those of Rugg et al. (1993) and a recent behavioral study by Weldon (1993), serve to emphasize that temporal factors are indeed likely to have an important role in mediating the impact of repetition on behavior. As noted already, in the present study the principal difference between the effects on ERPs of visual-auditory and auditory-auditory word repetition was in their onset latencies, rather than their magnitudes. And in a similar
vein, the effects of within-modality repetition of visual words and nonwords were differentiated as much or more by their onset latencies as by their magnitudes. It will be of interest to determine the extent to which the different behavioral consequences of these various forms of repetition are attributable to differences in the time course of the processes on which they exert an influence.

Finally, it is noteworthy that the auditory-visual repetition of words and nonwords gave rise to effects that were very similar in their time courses and scalp distributions, suggesting that these effects reflect the modulation of a common component or components. This finding stands in marked contrast to the effects of across-modality repetition on auditory ERPs when, as already noted, lexical status appears to play a critical role. Unfortunately, it is impossible to draw parallels between these results and those from analogous behavioral studies, since there is a dearth of work investigating the consequences of across-modality repetition of nonwords (although see Bowers, 1994). Taken at face value, the present findings lead to the prediction that, in contrast to what has been found with words, across-modality nonword repetition effects on behavior will be stronger in the auditory-visual direction than vice versa.

**ERP Repetition Effects**

Turning first to the auditory ERPs, the results point to the existence of at least two repetition-sensitive components, one of which is modality- but not lexically-sensitive, and the other the exact opposite. The level of abstraction of the processes reflected by the modality-dependent component seems likely to be relatively high. Rugg et al. (1993) were unable to find evidence of modality dependency in their auditory ERPs, indicating that visually and auditorily presented words can sometimes be encoded into forms that are equivalent from the perspective of the processes reflected by the ‘modality-dependent’ component of the auditory repetition effect.

The across-modality effects on auditory ERPs differ markedly between experiments in both onset latency and magnitude. One explanation of these results is that the across-modality effect depends on processing overlap at the semantic level, a locus available only for words. It is difficult, however, to reconcile this explanation with the pattern of results for the visual ERPs across the two experiments; if across-modality repetition effects are semantically mediated, why are they so much in evidence when nonword repetition is in the auditory-visual direction? An alternative explanation is that differences between word and nonword visual-auditory repetition effects reflect differences in the level at which these items can be represented phonologically. The phonological code generated in response to visually presented words will contact phonologically accessible lexical representations. So when the same word is presented auditorily, such representations can provide a locus for processing overlap. By contrast, the (nonlexical) phonological codes representing nonwords may be less invariant than those at the lexical level, and hence less likely to correspond closely to representations formed when the same items are presented auditorily.

Turning to the findings for visual ERPs, it is unclear to what extent the different patterns of visual-visual effect for words and nonwords signal the engagement of different neural systems by the two types of item. Although differing in onset latency and lateral distribution, the amplitude maxima of both effects were distributed more anteriorly than those of the corresponding across-modality effects. Thus it seems clear that the visual-auditory repetition of both words and nonwords engages different or additional ERP generators to those activated by auditory-visual repetition. On the basis of the available evidence, there is no reason to reject the possibility that at least some of these generators are shared.

The similar onset latencies and scalp distributions of the word and nonword auditory-visual repetition effects suggest that these effects do not rely on processing specific to either the lexical or semantic level. Rugg et al. (1993) argued that the auditory-visual repetition effect depended on the generation of a phonological representation of the visual input, which overlapped the representation formed when the item was initially presented auditorily. The present findings are consistent with this argument, and suggest that such representations need not be lexical. It remains to be established whether the component underlying this effect is sensitive specifically to repetition within the phonological domain.

The account given above of auditory-visual nonword repetition effects seemingly contradicts the explanation given earlier of the very weak effects observed in the opposite direction. If phonological representations of spoken nonwords are sufficiently durable and invariant to match those derived from subsequently presented visual nonwords, why does the reverse not apply, as indeed is the case with words? Two answers to this question seem possible. First, there could be a difference in the relative persistence of the phonological codes generated from auditory and visual nonwords, the latter for some reason being more ephemeral. A second, more interesting possibility is that the representation generated by the spoken form of a nonword primes or constrains the phonological coding of its written form, leading to the creation of closely corresponding phonological codes. To take an extreme example: hearing the spoken form jed may increase the probability of pronouncing the letter string JEAD as Jed rather than Jed. But it seems very unlikely that pronouncing JEAD as Jed would cause the spoken form Jed to be encoded as Jed.

The last issue to be discussed concerns the identity of
the ERP components responsible for the repetition effects observed in these experiments. It has been demonstrated previously (Rugg, 1990; Van Petten et al., 1991; Young & Rugg, 1992) that visual–visual ERP word repetition effects result from the modulation of at least two temporally and spatially overlapping components. It has been suggested that the earlier of these components corresponds to the heavily studied “N400” component, and the later one to the “P3” or “late positive component” (Rugg & Doyle, 1994; Van Petten et al., 1991). Clearly, the present data are consistent with the view that the ERP repetition effect reflects the modulation of multiple components. Indeed, these data suggest that, on a combination of topographical and functional criteria, three or more repetition-sensitive components can be identified in ERP waveforms.

The present findings thus underscore the power of ERPs to fractionate repetition-sensitive cognitive processes. They also illustrate the difficulty of attempting to describe such data by reference to the few repetition-sensitive components identified in previous experiments that have employed a more limited range of independent variables. There seems every reason to think that future research will uncover yet more repetition-sensitive processes whose neural correlates can be detected from the scalp. The challenge will remain to determine how these processes contribute to the behavioral consequences of repetition.

EXPERIMENT 1: METHOD

Subjects. Sixteen young adults (seven male, all righthanded) participated. They were each paid £3 per hour.

Stimuli. The words employed in this experiment were identical to those used by Rugg et al. (1993) and listed in the appendix of that paper. The critical stimuli were 192 open class words between 4 and 8 letters in length and with a frequency of occurrence of between 1 and 7 per million (Kucera & Francis, 1967). They were split into 4 sets of 48 items. A further 96 words with the same characteristics were divided into two sets of 48 items each, and used as auditory and visual filler items. Ninety-six animal names were also selected with the help of the same source. These varied in length between 4 and 9 letters, and in frequency between 0 and 49 occurrences per million (mean = 5.2). This “target” set was also divided into two subsets of 48 items each.

Stimulus lists were generated by assigning each of the four groups of 48 critical items to one of four repetition conditions. In two conditions, Visual → Visual and Auditory → Auditory, an item was presented in the same modality on both its first and its second presentation. In the other two conditions, Visual → Auditory and Auditory → Visual, the modality was changed between presentations. The critical items were combined in a pseudorandom order with 48 auditory and 48 visual animal name targets, and 48 auditory and 48 visual filler items, such that 6 items intervened between a critical item’s first presentation and its within- or across-modality repetition.

A stimulus list comprised 576 items, subdivided into 6 blocks of 96 items, each beginning with a filler. Four experimental lists were produced by rotating the four groups of critical stimuli so that, across lists, each item appeared in each of the experimental conditions. Another four lists of stimuli were produced by again rotating the four groups of critical stimuli through the four priming conditions, but using a different pseudorandom ordering of conditions. In this second set, the targets and fillers that had appeared in the visual modality in the first set were now presented in the auditory modality, and vice versa. Visual stimuli were presented on a Commodore 1084s monitor in white upper case letters on a black background. They subtended a maximum horizontal visual angle of 1.4° and a vertical angle of 0.4°. Auditory stimuli were digitized at 16kHz with 8 bit resolution, and stored on the hard disk of a Commodore Amiga B2000 computer. They were then edited so that the beginning of the stored sound segment corresponded to the onset of the word. The mean durations of the critical items in each of the four stimulus sets were 640, 677, 656, and 642 msec (range 279–999 msec). All items were spoken by a single male speaker.

Procedure. Subjects were seated in front of the computer monitor with their right index finger resting on a microswitch. They wore a set of headphones (Sennheiser HD40) through which the auditory stimuli were presented. Subjects were instructed to press the microswitch whenever they saw or heard an animal name, and were told they should try to respond quickly while making as few mistakes as possible. They were asked to remain relaxed and to keep looking at the position on the monitor occupied by the fixation point. They were also asked to refrain from blinking other than during the period when the fixation point was on the screen. The subjects were first presented with a practice list of 40 items, before proceeding to the main experimental list.

The fixation point on any trial was either an O or an X. An X indicated that the next stimulus would be a visual stimulus displayed on the screen, while an O indicated that the next item would be heard on the headphones. The fixation point was presented for 2.1 sec before the presentation of each stimulus, disappearing 102 msec before stimulus onset. Visual stimuli were presented for 300 msec, the screen remaining blanked for a further 1200 msec, after which the fixation point for the next trial was presented. Auditory stimuli were presented binaurally at a comfortable hearing level, the screen remaining blank for 1.5 sec from stimulus onset.
**ERPs.

**Procedure.** Subjects were instructed to respond either when they heard a word, or saw a nonword that sounded like a word. In all other respects, the procedure was identical to that followed in Experiment 1.

**ERP Recording.** All aspects of ERP recording and averaging were the same as in Experiment 1.

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**Notes**

1. In both experiments, ERPs evoked by first presentations of items subsequently repeated within- or across-modality did not differ, and they were therefore averaged together to yield a single waveform for first presentations in each modality.

2. A referee pointed out that the onset latencies of the auditory word repetition effects in both this study and Rugg et al. (1993) were 100 to 200 msec longer than those reported by Anderson and Holcomb (1992) for the modulation of auditory ERPs by cross-modality repetition. In the study of Anderson and Holcomb (1992), no items intervened between the critical item pairs, which in different conditions were separated by intervals varying from 0 to 800 msec. We have yet to study across-modality repetition over any inter item lag other than 6, so it is unclear whether the aforementioned between-study differences in the onset latencies of auditory repetition effects reflect the influence of inter item lag, other differences between the studies in experimental procedure, or (as the referee suspects) differences in the discriminability of the auditory material. Since nothing that we have to say is predicated on a direct comparison between the onset latencies of repetition effects in the visual and auditory modalities, this issue is not pursued further here.

3. This experiment was preceded by one in which visual targets were nonwords rather than pseudohomophones. The findings from that study were very similar to those described here, although the effects on visual ERPs were smaller in magnitude and of weaker statistical significance. The present experiment was performed to ensure that the very weak effects of visual-auditory repetition observed in the previous experiment were not attributable to a failure to encode visual nonwords phonologically. Since no difference was observed between experiments in the repetition effects on auditory ERPs, and the differences in the effects on visual ERPs are more quantitative than qualitative, only the second experiment is described here. It is, however, worth noting that in the preliminary experiment, detection of the visual word targets was considerably faster and more accurate than that of the pseudohomophones employed in the present Experiment 2 (RT = 750 msec, correct detections = 93%, false positives = 2%), while auditory target detection was very similar to that reported here. These levels of performance are similar to those reported for nonword targets by Rugg et al. (1993). Thus the marked differences observed between the results of that study and Experiment 1 on the one hand, and Experiment 2 on the other, are very unlikely to reflect between-study differences in task difficulty.
REFERENCES


