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The effects of divided attention on auditory priming

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Traditional theorizing stresses the importance of attentional state during encoding for later memory, based primarily on research with explicit memory. Recent research has begun to investigate the role of attention in implicit memory but has focused almost exclusively on priming in the visual modality. The present experiments examined the effect of divided attention on auditory implicit memory, using auditory perceptual identification, word-stem completion and word-fragment completion. Participants heard study words under full attention conditions or while simultaneously carrying out a distractor task (the divided attention condition). In Experiment 1, a distractor task with low response frequency failed to disrupt later auditory priming (but diminished explicit memory as assessed with auditory recognition). In Experiment 2, a distractor task with greater response frequency disrupted priming on all three of the auditory priming tasks as well as the explicit test. These results imply that although auditory priming is less reliant on attention than explicit memory, it is still greatly affected by at least some divided-attention manipulations. These results are consistent with research using visual priming tasks and have relevance for hypotheses regarding attention and auditory priming.

The concept of attention plays a central role in theories of memory, a view supported by a long history of findings that attentional state during encoding affects later memory performance (e.g., Broadbent, 1958; Cowan, 1995; Norman, 1969). Traditional research on this topic has focused on explicit memory. More recently, researchers have addressed the relationship between attention and implicit memory, spurred by the well-documented dissociations between implicit and explicit memory (Mulligan, 2003b; Roediger & McDermott, 1993), as well as the possibility that attention during encoding may not be as crucial to implicit memory as it is to explicit memory.

Several initial studies of attention and implicit memory reported the rather startling result that dividing attention reduced explicit test performance but left implicit tests unaffected (e.g., Bentin, Kutas, & Hillyard, 1995; Mulligan & Hartman, 1996; Parkin, Reid, & Russo, 1990; Parkin & Russo, 1990; Russo & Parkin, 1993; Schmitter-Edgecombe, 1996). Other early studies demonstrated that retention of very poorly attended stimuli is more likely to be detected with implicit than explicit memory tests (e.g., Bornstein, Leone, & Galley, 1987; Eich, 1984; Jelicic, Bonke, Wolters, & Phaf, 1992; Mandler, Nakamura, & Van Zandt, 1987; Merikle & Reingold, 1991; cf. Berry, Shanks, & Henson, 2006). Such findings imply that attention plays a larger role in encoding for explicit than implicit memory. Other researchers have gone farther in interpreting these results, proposing that implicit memory is chiefly the result of automatic encoding processes (the automaticity hypothesis, e.g., Aloisi, McKone, & Heubeck, 2004; Bentin et al., 1995; Parkin et al., 1990; Shallice et al., 1994; Szymanski & MacLeod, 1996; Wolters & Prinsen, 1997). Much subsequent research on this topic took place under the rubric of the transfer-appropriate-processing (TAP) view of implicit and explicit memory (e.g., Roediger, 1990; Roediger & McDermott, 1993), which provides a more differentiated view based on the distinction between conceptual and perceptual priming. This view suggests that implicit tests drawing heavily on conceptual processes should depend heavily on attention during encoding. However, perceptual priming tasks, sensitive to relatively automatic perceptual encoding processes (Roediger, 1990), should be little affected by manipulations of attention (see Mulligan & Hartman, 1996, for a more detailed development of the TAP predictions). With respect to conceptual implicit memory, these expectations are largely borne out: divided attention typically reduces conceptual priming (see Mulligan & Brown, 2003, for a review).

Studies of perceptual implicit tests, however, have produced mixed results. As noted above, some of the initial studies on this topic found no effect of divided attention on perceptual priming despite robust effects on explicit memory (e.g., Mulligan & Hartman, 1996; Parkin et al., 1990; Parkin & Russo, 1990; Russo & Parkin, 1993). For example, in Mulligan and Hartman (1996), study words were presented visually under one of two conditions. In the full attention (FA) condition, the participants' sole task was to read the words, whereas in the divided attention (DA) condition, participants read the words and simul-

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taneously monitored aurally presented digits for runs of three odd numbers in sequence (the three-odd task). Participants were later presented with either word-fragment completion (an implicit test) or its explicit counterpart, word-fragment cued recall. Priming in word fragment completion was unaffected by divided attention whereas cued recall was substantially reduced. In a similar experiment, Mulligan (2003a) found that the same DA task reduced later recognition memory but left priming in the perceptual identification task unaffected.

Other studies have reported substantial effects of attentional manipulations on perceptual priming (e.g., Crabb & Dark, 1999, 2003; Hawley & Johnston, 1991; Rajaram, Srinivas & Travers, 2001; Stone, Ladd, Vaidya, & Gabrieli, 1998). Mulligan (2003a; see also Mulligan, 2002; Mulligan & Hornstein, 2000) identified some of the factors determining whether attentional manipulations affect perceptual priming. First, selective-attention manipulations can impair perceptual priming. In these manipulations, attention is directed away from the stimulus (e.g., word) that is to be tested later; typically the participant is directed to ignore the study word and respond to a distractor stimulus instead (e.g., as in a flanker task). Selective attention manipulations may exert their effects, at least in part, by disrupting stimulus identification and lexical processing, which are critical for perceptual priming (e.g., Fay, Isingrini, & Clarys, 2005; Richardson-Klavehn & Gardiner, 1998; Weldon, 1991). Second, certain dual-task (i.e., divided attention) manipulations can also impair later perceptual priming. In divided-attention manipulations, the participant is directed to attend to (and typically respond to) multiple stimuli; that is, the participant typically reads the study words and responds to stimuli from the DA task. Mulligan (2003a) found that dual-task manipulations requiring infrequent responses to distractors (even those with high working memory load, such as the three-odd task) produce little effect on perceptual priming. However, dual-task manipulations which require frequent responses to distracting stimuli (even with little of no working memory load) can disrupt perceptual priming (see also Mulligan & Hornstein, 2000; this notion is discussed in greater detail in the introduction to Experiment 2).

This progression of research makes clear that attentional manipulations can have large effects on perceptual priming, and delineates some of the conditions producing these effects. Despite this progress, our understanding of the relationship between attention and implicit memory is only partial because all of the research on divided attention and perceptual priming has used visual priming tasks. The present study examines the effects of divided attention on auditory priming tasks. This is critical because perceptual priming exhibits great stimulus- and modality-specificity (Schacter, Dobbins & Schnyer, 2004). This specificity suggests that visual and auditory priming entail modality-specific encoding operations (Schacter et al., 2004), and there is no guarantee that these different operations have a similar dependence on attention. In addition, the standard multiple-memory systems account of implicit memory (e.g., Schacter, Wagner & Buckner, 2000) attributes perceptual priming to the operation of Perceptual Representation Systems (PRS), a collection of domain-specific processing modules which represent information about the form and structure of words and objects. Critically, it has been proposed that separate PRS modules process visual and auditory word-form information (Schacter, 1994; Schacter et al., 2000; Verfaellie, Keane, & Johnson, 2000).[1] Thus, at a general level, given the modality- and domain-specificity of perceptual priming, it is important to determine if the effects of critical variables (such as attention) produce the same effects on priming in the auditory modality as in the visual modality.

More specifically, Bentin et al. (1995) found similar levels of priming in auditory lexical decision for words presented in the attended and unattended channel in a dichotic-listening paradigm, raising the possibility that auditory priming may be less attention-demanding than visual priming (see also Eich, 1984; cf. Wood, Stadler, & Cowan, 1997). Likewise, Carlesimo et al. (2000) suggested that auditory priming reflects automatic encoding processes more so than visual priming because auditory priming relies on perceptual skills that are more greatly overlearned and mastered earlier in life than the perceptual skills underlying visual priming with words. Consistent with this notion, these authors found that auditory priming exhibited developmental invariance across first- through fifth-graders whereas visual priming increased with age.

As researchers refined their methods, it became clear that visual priming is affected by divided attention. The work of Bentin et al. (1995) and Carlesimo et al. (2000) suggest that auditory priming may not be as sensitive to divided attention. That is, a more complete assessment of the automaticity hypothesis requires the use of auditory priming tasks. The automaticity hypothesis suggests that divided attention should leave auditory priming unaffected. On the other hand, auditory and visual priming exhibit a number of similarities which we review next. These similarities suggest that auditory priming may exhibit the same sensitivity to divided-attention manipulations as does visual priming.

Although the vast majority of research on implicit memory has focused on visual priming tasks, there is a growing body of research on auditory priming. Examples of auditory implicit tests include auditory versions of word-stem completion (in which the participant hears the first portion of a word and completes it with the first word that comes to mind) and word-fragment completion (in which fragments of words, interspersed with silence, are completed). Another example is auditory perceptual identification, in which participants attempt to identify spoken words that are perceptually degraded (e.g., by low-pass filtering or masking with random noise).

Research using auditory tasks shows them capable of uncovering implicit influences of memory. For example, in Schacter, Church, and Treadwell's (1994) study, amnesic patients demonstrated normal levels of priming in auditory perceptual identification coupled with reduced explicit memory (on an auditory recognition test) compared to control participants, indicating that intact perceptual priming in amnesia extended to the auditory domain. Likewise, patients with Alzheimer's disease (AD) exhibit preserved auditory priming relative to healthy age-matched controls, despite impaired recognition memory (Verfaellie et al., 2000). Similar dissociations have been documented with respect to healthy aging; compared to younger adults, older adults typically exhibit significant decrements in explicit memory and little or no decrement in auditory priming (e.g., Pilotti & Beyer, 2002).

Functional dissociations between auditory priming and explicit memory have also been reported. For example, manipulations of conceptual encoding (e.g., the levels-of-processing manipulation) typically enhance performance on explicit tests but have little effect on auditory priming (Schacter & Church, 1992). In contrast, perceptual manipulations typically affect auditory priming. For example, auditory study produces greater priming than visual study on priming in auditory perceptual identification and stem completion (e.g., Loveman, van Hoof, & Gale, 2002; Pilotti & Beyer, 2002). In addition, Church and Schacter (1994) found that changes in the speaker's voice, intonation, and fundamental frequency between study and test reduced auditory priming yet had little effect on explicit memory.

Although different auditory priming tasks generally produce consistent results, this is not always the case. For example, in Pilotti et al. (2000), study words were presented visually or aurally in one of two voices, followed by one of four auditory implicit tests: identification of words presented in white noise, identification of words with low-pass filtering, word-stem completion, and word-fragment completion. The test items were presented in either the studied voice or a different voice. All four implicit tests exhibited a modality effect: greater priming for auditory than visual study words. Furthermore, the two identification tasks exhibited a voice effect (greater priming for the same than different voice) whereas the two completion tasks were unaffected by voice change.

In sum, auditory priming generally exhibits similar functional and population dissociations as visual priming tasks. In addition, auditory priming exhibits a lack of sensitivity to conceptual encoding manipulations coupled with a sensitivity to perceptual encoding manipulations (such as study modality), implying that these tasks exhibit the characteristics of perceptual implicit tests in terms of the TAP framework (Church & Schacter, 1994; Pilotti et al., 2000). However, some differences have been observed between auditory and visual priming tasks (e.g., Carlesimo et al., 2000; McClelland & Pring, 1991). In addition, dissociations among auditory priming tasks have also been uncovered (Blum & Yonelinas, 2001; Pilotti et al., 2000).

The goal of the present experiments is to determine whether auditory priming tasks exhibit the same pattern of DA effects (and noneffects) as visual priming tasks. As noted earlier, dual-task manipulations that require infrequent responses to distractors (even those with high working memory load) produce little effect on visual priming whereas distractor tasks requiring more frequent response disrupt later visual priming (Mulligan, 2003a; Mulligan & Hornstein, 2000). In two experiments, the role of attention in auditory priming was assessed by comparing full and divided attention during encoding on later auditory priming. A variety of auditory implicit memory tests were used (perceptual identification of low-pass filtered words, word-stem completion, and word fragment completion) because dissociations are sometimes found among auditory priming tasks. The use of several implicit tests allows us to assess the generality of any DA effects that are observed. An explicit test of auditory recognition was also included to verify the expected negative effects of DA on explicit memory.

Experiment 1 made use the three-odd task to divide attention during encoding. The three-odd task is something of a standard divided-attention manipulation in memory research (e.g., Craik, 1982; Fernandes & Moscovitch, 2000; Gabrieli et al., 1999; Jacoby, 1991; Jacoby et al., 1989; Mulligan, 1998, 2003a; Schmitter-Edgecombe, 1999). More importantly for present purposes, this DA manipulation is known to leave priming unaffected in visual perceptual identification and word-fragment completion (Mulligan, 2003a; Mulligan & Hartman, 1996). Experiment 1 determines if this manipulation likewise leaves auditory priming unaffected while simultaneously disrupting explicit memory.

EXPERIMENT 1

Method

Participants. Eighty-eight undergraduates at the University of North Carolina participated in exchange for credit in psychology classes.

Design and Materials. The experiment used a 2 × 4 design in which attention at encoding (full vs. divided) was manipulated within subjects and the type of memory test (low-pass filtered word identification, word-stem completion, word fragment completion, and recognition) was manipulated between-subjects. The critical items were 120 common polysyllabic words (M = 17.16, SD = 11.62; Francis & Kučera, 1967). The items were randomly divided into two sets of 60 to counterbalance across the studied (old) and new condition. Both sets were further randomly divided into lists of 30 for the full and divided attention blocks of the experiment (2 buffer items, similar in length and frequency to the critical items, were presented at the beginning and end of each block). The implicit tests consisted of all 120 critical items (60 old and 60 new items, randomly intermixed), preceded by two practice and three filler items of similar length and frequency, for a total of 125 test trials. The auditory recognition test consisted of only the 120 critical items. The study words were recorded to audio files and played over headphones. Pilot testing ensured that the words were understandable.

Words were presented in the clear during the study portion and during the recognition test. The words in the low-pass filtering condition were degraded by filtering the items at 1 kHz (low-pass filtering eliminates high frequencies rendering a speech signal that sounds muffled). Word stems consisted of the initial syllable of the target word followed by silence. Word fragments were created by replacing at least two portions of the speech signal with equivalent durations of silence. The silences were in medial portions of the word and did not include the initial or final phonemes. All of the test stimuli were created by modifying the original speech recordings using the Goldwave program (ver. 5.08, 2004). The test materials were modeled on those used in prior research on auditory priming (Pilotti et al., 2000) and were piloted to produce accuracy rates for new items in the range of .3–.5, a level that minimizes the possibility of floor or ceiling effects.

The divided attention condition used the three-odd task (as in Mulligan & Hartman, 1996). Participants monitored a series of random digits, presented on a computer screen, and attempted to detect target sequences of three odd digits in a row. The digits were displayed at a rate of one digit per 1.5 sec. There were 10 target sequences randomly distributed in the series of 68 digits, subject to two constraints: (1) a minimum of one digit and a maximum of five digits occurred between the end of one target sequence and the beginning of the next, and (2) not more than two even digits occurred in sequence.

Procedure. Participants were tested individually. The experiment began with the study phase, in which each study word was played through headphones at a rate of one word per 3 sec. Participants were instructed to repeat each word after hearing it, to ensure that the words were understood. This was the sole task in the full attention portion of the study phase. During the divided attention condition, participants were instructed to simultaneously repeat the words and perform the digit-monitoring task. Participants were instructed to monitor the digits for strings of three odd numbers in a row and to respond with a keypress on the computer whenever they detected a target string. If a participant missed a target sequence, the computer prompted the participant by displaying a large red "X" in the location of the digit for 150 msec. The computer recorded the errors made during target sequence detection, and the experimenter monitored the accuracy in repetition during study. Task instructions emphasized that repeating the words and performing the digit-monitoring task were equally important. Participants had 30 sec of practice on the digit-monitoring task prior to the start of the divided attention study list. The order of the attention blocks was counterbalanced across participants.

Next, the participants performed two 3-min filler tasks designed to minimize any recency effects and mask the purpose of the impending implicit test. The first task was a sheet containing basic arithmetic problems (e.g., 35 + 46 = ___). The participants were instructed to complete as many of the problems as they could, without making any written calculations. The second task was a city-name completion sheet, which listed stems of city names (e.g., Bos___ for Boston). Participants were instructed to complete each stems with the name of a U.S. city. Following these tasks, the test was administered.

Participants in the implicit condition were informed that the next portion of the experiment was a perceptual task. No mention was made of the earlier study phase. Participants in the low-pass filtered condition were presented with perceptually degraded words and instructed to try identify each. Individuals in the word-stem completion and the word fragment completion tests were told to complete the stem or fragment with the first word that came to mind. Participants wrote their responses on a sheet of paper. The instructions for these implicit tests made no mention of the prior study list. For the recognition test, participants were informed that their memory for the study words would be tested. Participants were presented with the test words over headphones, and reported their answers by writing "O" (for old) or "N" (for new) on their test sheets. All of the test trials proceeded at a participant-determined rate (pressing the Enter key initiated the presentation of the next trial). Each implicit test was presented to 24 participants, and 16 participants took the recognition test. Larger sample sizes were used for the implicit tests to increase the power in those conditions.

Results and Discussion

During the study task, participants identified all of the study words correctly in both the full- and divided-attention conditions. Performance on the three-odd task was assessed by calculating the proportion of correct responses for the target sequences. The mean proportions for the low-pass filter, word stem completion, word fragment completion, and recognition tests were .93, .97, .94, and .93, respectively ($F < 1$) (an alpha-level of .05 was used unless otherwise noted).

The proportions of the critical old and new words that correctly identified or completed are presented in Table 1. Accuracy on implicit tests is measured with priming scores (the difference between old and new identification or completion rates) whereas accuracy on the explicit recognition test is measured with the signal detection measure, d'. Because priming and d' constitute different measurement scales, the implicit and explicit test results were analyzed separately. First, priming scores on the implicit tests were analyzed with a 2 × 3 ANOVA, using attention (full vs. divided) as a within-subjects factor and type of test (low-pass filtered word identification, word-stem completion and word fragment completion) as a between-subjects factor. Critically, there was no significant effect of attention ($F < 1$), indicating that priming did not differ across the full and divided attention conditions. Of less importance was the main effect of test type [$F(2,69) = 5.74$, $MS_e = .025$], indicating that the average amount of priming varied across tests (and was highest for word-stem completion). Finally, the interaction between attention and test type was not significant although it approached the traditional criterion ($F = 2.34$, $p = .10$). In light of the nearly significant interaction, it seemed prudent to examine the effect of attention on each test individually. Consistent with the primary analysis, none of the implicit tests exhibited an effect of attention; priming in the FA and DA conditions did not significantly differ on any of the tests ($|t|$s < 1.4, ps $> .15$). Finally, analyses were carried out to determine if priming was significantly greater than zero. Within each test condition, two analyses compared the old and new rates

Table 1
Mean Proportions Identified or Completed (and Standard Deviations) As a Function of Encoding Status

	Full Attention		Divided Attention		New	
Test	*M*	*SD*	*M*	*SD*	*M*	*SD*
Experiment 1						
Low-pass filter word ID	.49	.15	.53	.11	.38	.11
Word-stem completion	.60	.12	.59	.13	.35	.10
Word-fragment completion	.66	.11	.64	.11	.48	.09
Experiment 2						
Low-pass filter word ID	.65	.13	.59	.10	.48	.11
Word-stem completion	.60	.14	.53	.15	.34	.12
Word-fragment completion	.67	.11	.60	.14	.43	.11

(separately for the FA and DA conditions). The analysis revealed significant priming in every FA and DA condition [$t(23)$s > 5.5].

In contrast to the results with the implicit tests, auditory recognition exhibited a significant effect of divided attention. The mean hit rates for the full and divided attention were .83 and .71, with a false alarm mean of .18. Recognition accuracy (as measured by d') was significantly higher in the full than divided attention condition [$t(15) = 4.04$, 1.98 vs. 1.58].

The results of this experiment are consistent with those of Mulligan (2003a) and Mulligan and Hartman (1996), demonstrating that the three-odd task produces a robust effect on explicit memory but no significant effect on perceptual priming. In the prior research, these results were obtained with visual priming tasks and in the present case with several auditory priming tasks. Before continuing, it is worth noting that the results are unlikely due to low power in the implicit test conditions. First, the implicit test conditions had more participants than the recognition condition and yet failed to show an effect of divided attention. Furthermore, a formal power analysis indicates substantial power for each implicit test. Specifically, the size of the attention effect on auditory recognition was $d = 1.01$. The power to detect an effect of that size for each of the implicit tests individually ($n = 24$, $\alpha = .05$, one-tailed) was .96. The combined analysis, of course, had even greater power, exceeding .99 to find an effect of attention the size of that found in the explicit condition. Furthermore, this analysis had power of .91 of finding an effect one-half the size of that found in recognition. Consequently, a lack of power in the implicit test conditions is not likely the cause of the present dissociation between auditory implicit and explicit memory tests.

EXPERIMENT 2

Experiment 1 provides preliminary evidence that manipulations of divided attention produce similar effects on visual and auditory priming tasks; the three-odd task failed to disrupt auditory priming, as it fails to disrupt visual priming, despite producing robust effects on (visual or auditory) explicit memory tasks. Experiment 2 extends this investigation by determining if a divided-attention task known to disrupt visual priming likewise disrupts auditory priming. This is important for two reasons. First, it continues the evaluation of the comparability of visual and auditory priming with respect to attention. Second, it is critical for fully evaluating the role of attention in auditory implicit memory. Specifically, the results of Experiment 1 might be taken to indicate that auditory priming reflects automatic encoding processes, as suggested by the automaticity hypothesis and more narrowly by the TAP account with regard to perceptual priming tasks. As noted earlier, however, research with visual priming tasks generally does not support this view. Some divided-attention manipulations disrupt visual priming tasks contrary to the automaticity hypothesis.

In response to such results, Mulligan (2003a, Mulligan & Hornstein, 2000) proposed a distractor-selection hypothesis which suggests that selecting a distractor for response disrupts encoding of the target stimulus. This hypothesis was motivated by the central bottleneck model of Pashler (1994, 1998), a model based on evidence from the psychological refractory period (PRP) methodology. This theory proposes that memory encoding requires a central (amodal) bottleneck process, a bottleneck that also subserves response selection and memory retrieval (see also Arnell & Jolicœur, 1999; Dell'Acqua & Jolicœur, 2000). This view argues that selecting a response to a distractor is a source of disrupted memory encoding. According to this view, divided-attention effects should be most evident when the response to the distractor is contemporaneous with target encoding.

According to the distractor-selection hypothesis, if responses to the distractor task are infrequent or do not occur during target encoding, then the divided-attention task is less likely to produce effects (because it is less likely to compete for the central process bottleneck as memory encoding occurs). In the typical implementation of the three-odd task, response selection is relatively infrequent. An overt response need only be made after a string of three odd digits is detected. In Experiment 1, participants in the divided-attention conditions rendered overt responses every 9 sec on average. In Experiment 2, the distractor task presented the same sequence of digits but required an odd-even decision on each trial. Coupled with a more rapid presentation of the distractor digits (1/sec), this represents a nine-fold increase in the frequency of overt responses to distractors. Most importantly for present purposes, this variant of the distractor task is known to produce a significant reduction in later visual priming (Mulligan, 2003a). The present experiment determines if the same is true of auditory priming tasks.

Method

Participants. One hundred undergraduates at the University of North Carolina participated in exchange for credit in psychology classes.

Design, Materials, and Procedure. Experiment 2 used the same design and materials as Experiment 1. The procedures were likewise the same except for the changes to the study phase. In the divided-attention condition, the digits were presented on the computer screen at a rate of one every second. Participants were instructed to classify each digit as even or odd by pressing the "e" or "o" key, respectively. If a participant made an error or failed to respond within 1 sec of the onset of the digit, the computer displaying a large red "X" in the location of the digit for 150 msec. As in Experiment 1, task instructions emphasized that repeating the words and performing the digit-monitoring task were equally important. Participants had 30 sec of practice on the digit-monitoring task prior to the start of the divided-attention study list. Twenty-four participants took part in each test condition with the exception of word-stem completion, which had 28 participants.

Results and Discussion

During the study task, participants identified all of the study words correctly in both the full- and divided-attention conditions. On the odd–even task, mean proportions correct did not differ across test conditions, .89, .89, .85 and .88, for the low-pass filter, word fragment completion, word stem completion, and recognition tests, respectively ($F < 1$).

The implicit test results are presented in Table 1. Priming scores on the implicit tests were analyzed with a 2 (attention) × 3 (implicit test) ANOVA and revealed a significant effect of attention [$F(1,73) = 28.55$, $MS_e = .006$], indicating greater priming in the FA than DA condition. The main effect of test type was not significant (although it approached the traditional criterion, $F = 2.52$, $p = .09$). The attention-by-test interaction was not significant ($F < 1$).[2] Within each implicit test, priming was significantly greater than zero in both the FA and DA conditions (ts > 4.0). In contrast to the results of Experiment 1 using the three-odd task, the DA task of Experiment 2 significantly reduced priming. To further corroborate the differential impact of the DA manipulation in the present experiment, a cross-experimental analysis was carried out in which priming scores were analysis with a 2 (attention) × 2 (Experiment 1 vs. 2) × 3 (implicit test) ANOVA. The analysis revealed a significant interaction between attention and experiment [$F(1,142) = 14.63$, $MS_e = .006$], indicating that the effect of the attentional manipulation on priming was greater in Experiment 2 than in Experiment 1 (where it was nonsignificant). Attention was not involved in any other interactions (ps > .15).

Not surprisingly, the explicit test of auditory recognition was likewise affected by divided attention. The mean hit rates for the full and divided attention were .79 and .66, with a false alarm mean of .13. Recognition accuracy (as measured by d') was significantly higher in the full than divided attention condition [$t(23) = 4.36$, 2.14 vs. 1.69].

In contrast to the results of Experiment 1 using the three-odd task, all of the implicit tests in Experiment 2 exhibited a divided-attention effect as, of course, did the recognition test. This results is important for several reasons. First, it demonstrates that auditory priming is affected by a divided-attention manipulation, providing evidence against that notion that auditory priming reflects automatic encoding processes. Second, all of the auditory priming tasks were affected by the manipulation, indicating consistency in the effect of the attentional manipulation on auditory priming tasks. Third, the odd-even task produced the same negative effects on auditory priming as it produces on visual priming.

GENERAL DISCUSSION

The primary goal of the present experiments was to determine if auditory priming tasks exhibit the same sensitivity (and lack of sensitivity) to attentional manipulations as visual priming tasks. Toward this end, two secondary tasks with known effects on visual priming were used to divide attention during encoding. The three odd task of Experiment 1 failed to affect priming on three auditory priming tasks, perceptual identification (of low-pass-filtered words), word-stem completion and word-fragment completion. A secondary task requiring more frequent response selection (the odd-even task of Experiment 2) produced a significant reduction on subsequent priming on all three auditory priming tasks. Not surprisingly, both divided-attention manipulations decreased explicit memory in the auditory recognition test. These results are consistent with prior research on visual priming tasks, which has demonstrated that perceptual priming is unaffected by the three-odd task but substantially impaired when attention is divided with the odd-even distractor task (e.g., Mulligan & Hartman, 1996; Mulligan, 1998, 2003a).

An important consideration in research on implicit memory is the issue of explicit contamination on the memory tests. That is, it is possible that participants may have used explicit retrieval strategies to influence performance on the nominally implicit memory tests. In the present case, we have followed the design considerations of Roediger and McDermott (1993) to minimize this possibility. Following the guidelines of Roediger and McDermott, the present experiments had the following features: (1) the study (and test) instructions were incidental; (2) the test instructions emphasized providing the first response that came to mind; (3) multiple filler tasks intervened between the study and test portion of the experiment; (4) the set of study items is relatively large (greater than the recommended 50 items); (5) the proportion of old items on the test was below 50%; and (6) the test began with filler items not from the study portion of the experiment. Roediger and McDermott argued that these design features limit both the likelihood and utility of explicit contamination. Furthermore, Experiment 1 exhibits a dissociation between an auditory explicit memory test (recognition) and the auditory implicit tests. Given that the divided-attention condition has a substantial impact on explicit memory, it seems likely that if explicit retrieval played a role on the implicit tests, these tests would likewise exhibit an effect of divided attention. There was no evidence of such an effect, indicating that explicit contamination played little role on the auditory priming tasks.[3]

In addition to demonstrating that attentional manipulations produce similar effects on visual and auditory priming, the present results have implications for the relationship between auditory priming and attention. First, like visual priming, perceptual priming in audition appears to be less sensitive to attentional manipulations than explicit tests. The results of Experiment 1 indicate that a distractor task capable of reducing explicit memory produced no measurable effect on auditory priming. On the other hand, the results of Experiment 2 make clear that auditory priming, like visual priming, does not reflect automatic encoding processes. That is, auditory and visual priming may be less sensitive than explicit memory to some manipulations of attention but in other cases are quite sensitive to attentional manipulations.

As noted in the introduction, it has often been suggested that implicit memory is chiefly the result of automatic encoding processes (the automaticity hypothesis, e.g., Aloisi et al., 2004; Bentin et al., 1995; Parkin et al., 1990; Shallice et al., 1994; Szymanski & MacLeod, 1996; Wolters & Prinsen, 1997). The results of the present experiments argue against the automaticity hypothesis for auditory priming, just as earlier research provides evidence against this notion with respect to visual priming (e.g., Mulligan, 2003a;

Mulligan & Hornstein, 2000). This is especially noteworthy given that words might be expected to be more automatically encoded in the auditory than visual modality, and thus the resulting priming might be less likely to exhibit the effects of attentional manipulations in the auditory than visual domain (e.g., Bentin et al., 1995; Carlesimo et al., 2000; Eich, 1984). In this sense the present study provides more favorable conditions for the automaticity hypothesis, yet this hypothesis is still found wanting.

The present results are also inconsistent with the TAP analysis of attention and implicit memory (Mulligan & Hartman, 1996; Roediger & McDermott, 1993). In particular, it is traditionally assumed that dividing attention at study reduces the amount of semantic or conceptual processing (e.g., Broadbent, 1971; Craik, 1982; Craik et al., 1996; Norman, 1969). If the effects of divided attention are restricted to disrupted conceptual processing (leaving the perceptual processing of the stimulus unaffected), then the TAP view suggests that perceptual priming tasks should be unaffected. This implies that divided attention should reduce priming on conceptual tests but should not diminish perceptual priming. In the present case, we know that participants successfully identified the study words in the DA condition (i.e., perceptual processing was completed in the sense that the stimulus was identified). Despite this, divided attention reduced priming in three different auditory, perceptual tasks (Experiment 2), contrary to the TAP analysis.

The component processing view provides a related account of priming (e.g., Fernandes, Moscovitch, Ziegler, & Grady, 2005; Vriezen, Moscovitch, & Bellos, 1995), arguing that test performance is a result of a set of component processes (e.g., visual or auditory feature analysis, lexical access, semantic access, etc.), and that priming occurs to the extent that the critical components were performed during encoding. Furthermore, Vriezen et al. adopted a hierarchical analysis and suggested that priming may not occur if a memory test requires a higher level of processing (e.g., semantic access) than a study task (e.g., an encoding condition requiring only lexical access). A component processing view might argue that the DA condition limited encoding to a lower level of analysis than required for complete priming on the implicit tests. This seems possible, but the application of this view in the present case (in which the priming tasks are perceptual) is problematic. Perceptual priming for words requires perceptual analysis and lexical access but is little affected by variation in semantic analysis (e.g., Fay et al., 2005; Richardson-Klavehn & Gardiner, 1998; Weldon, 1991). The DA condition in the present experiments required overt word identification in both experiments (implying both perceptual analysis and lexical access). Under this analysis, the component processing account makes the same prediction as the TAP view, expecting no DA effect in either experiment. Further articulation of a component processing view requires a principled characterization of the critical process that was successfully carried under the three-odd task of Experiment 1 but not under the odd-even distractor task in Experiment 2.

The present study also has implications for a distinction raised by Gabrieli et al. (1999; Fleischman et al., 2001; Prull, 2004). On the basis of both neurological and functional dissociations, Gabrieli et al. suggested a distinction between production and identification priming tasks. Production tasks are those in which test cues do not uniquely define the information to-be-retrieved, but merely delimit a class of correct responses (such as word-stem completion). In identification tasks, participants merely identify a test stimulus and are assessed on speed or accuracy. In these tasks, the retrieval cue uniquely determines, or directly guides, retrieval of a single appropriate response (perceptual identification tasks fall into this category). Because there is a single correct answer for each retrieval cue, Gabrieli et al. (1999) characterized these tests as noncompetitive retrieval tasks. Gabrieli et al. (1999; Vaidya et al., 1997) argued that production priming tasks, but not identification-retrieval tasks, are sensitive to division of attention during encoding. Vaidya et al. (1997) suggested that simply accessing the target item during encoding results in full priming in later identification-retrieval tasks (similar to the TAP view, above); additional elaboration does not further enhance priming in such tasks. On the other hand, production priming tasks would benefit from elaboration beyond stimulus identification at encoding. According to this view, because division of attention is expected to disrupt elaboration, it should affect later production but not identification priming.

The present results are inconsistent with this expectation. Perceptual identification and word fragment completion are typically categorized as identification tasks because there is a single correct response for each test cue. Consequently, these tasks are expected to be generally insensitive to divided-attention manipulations (Gabrieli et al., 1999). Of course, these tasks were both affected by the DA manipulation in Experiment 2. In addition, both tasks produced the same pattern of effects and noneffects of DA as the word-stem completion test, a test classified as production because the word stems allow for multiple correct completions. The present experiments indicate no differential sensitivity for the production versus identification tasks in the auditory modality.

As noted in the introduction to Experiment 2, effects of divided attention on perceptual priming have been interpreted in terms of the distractor selection hypothesis (Mulligan, 2003a). Although the present experiments were not designed to directly test this hypothesis (see Mulligan, 2003a; Mulligan & Hornstein, 2000 for a more direct evaluation), the results are consistent with it. This hypothesis was motivated by the central bottleneck model of Pashler (1994, 1998). Research on the PRP, the attentional blink and visual encoding imply a central processing bottleneck that encompasses such processes as response selection, memory retrieval, and memory encoding (Arnell & Jolicœur, 1999; Dell'Acqua & Jolicœur, 2000; Pashler, 1994, 1998). When distractors require frequent responses and when distractors and targets are presented simultaneously, then the process of selecting a response to the distractor is most likely to disrupt memory encoding of the target. Alternatively, if responses to the distractors are infrequent and do not occur during target encoding, little effect of the divided-attention manipulation may be observed. The three-odd task used in Experiment 1 requires relatively infrequent response selection (in terms of overt responses). In contrast, the odd-even distractor task of Experiment 2 requires much more frequent responses to the distractor digits. Consequently, the distractor-selection hypothesis argues that the latter task should be more likely to produce a divided-attention effect on priming tasks.

An account of the relationship between attention and implicit memory based on Pashler's (1994, 1998) central-bottleneck theory would of course require further specification. For example, additional detail is necessary to account for the observation that a single attentional manipulation may produce different effects on different types of memory tests. For instance, the three-odd task reduces performance on explicit and conceptual implicit tests but not on visual and auditory priming tasks. Mulligan and Hornstein (2000) speculated that memory tests that rely more heavily on strategic encoding processes (e.g., elaborative and organization) may be more sensitive to manipulations of attention because such strategic-encoding processes require frequent memory retrieval and reencoding, often in a structured sequence. In terms of the central-bottleneck hypothesis, these strategies rely so heavily on the bottleneck that even infrequent competition, because of the infrequent response requirements of the three-odd task, may be sufficient to disrupt these encoding strategies. This account is speculative but is consistent with the finding that memory tests that rely heavily on elaborative encoding processes make greater use of central resources during encoding (e.g., Craik et al., 1996).

Of course, because the present experiments were primarily designed to determine if auditory priming tasks were affected by DA manipulations in the same way as visual priming tasks, the present results may not be uniquely supportive of the distractor-selection hypothesis. For example, one might think that the simple strength or difficulty of the secondary task accounts for the present results. That is, one might argue that weaker manipulations of attention impair explicit memory but not perceptual priming whereas stronger manipulations affect both explicit memory and priming (e.g., Wolters & Prinsen, 1997). This analysis would argue that the three-odd task is the weaker and the odd-even task the stronger manipulation of attention. Although this seems plausible, additional consideration of this view raises questions about its aptness in the present case. First, on a priori grounds, it is difficult to make a clear case that the odd-even task is actually more difficult than the three-odd task in a unidimensional sense. Both tasks require evaluating each digit as odd or even but only the three-odd task has the additional requirement of maintaining and updating the number of prior odd numbers, a memory-load component not required in the odd-even task. From this perspective, it might be argued that the three-odd task should produce a "stronger" manipulation of attention. Second, an alternative assessment of the two DA manipulations is to examine their effects on the recognition test. If the odd-even task is the stronger manipulation of attention, it might be expected to produce a larger effect. However, the measures of effect size indicate that the two manipulations produced comparable effects on recognition. In fact, the three-odd task produced a numerically larger effect (the effect sizes of divided attention on recognition were $d = 1.01$ and $d = 0.89$ in Experiments 1 and 2, respectively).[4] These a priori and empirical considerations do not support a simple strength account of the present results, arguing instead for a more detailed analysis of the effects of distractor tasks as provided by the distractor-selection hypothesis.

Finally, the present results add to the documented similarities between visual and auditory priming. Although there are some differences in priming across-modalities (e.g., Carlesimo et al., 2000; McClelland & Pring, 1991), visual and auditory share many similarities. For example, visual and auditory priming are similarly preserved in populations (amnesics, Alzheimer's Disease) with compromised explicit memory. Likewise, several experimental variables (study modality, levels-of-processing) produce similar effects on visual and auditory priming. To this list of similarities can be added the effects of divided attention.

AUTHOR NOTE

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NOTES

1. Neuroimaging and neuropsychological research provide conflicting evidence on the separability of the neural substrates of visual and auditory priming. Some studies indicate common brain areas (e.g., Badgaiyan, Schacter, & Alpert, 2001; Swick et al., 2004) and other research implicates separate brain regions for visual and auditory priming (e.g., Bergerbest et al., 2004; Carlesimo et al., 2004; Samuelson et al., 2000).

2. It should be noted that the effect of attention on priming was significant within each test as well, $t\text{s} > 2.60$.

3. It should be noted that we did not include a matching explicit test for each implicit test in our study. Although this is often desirable in research on implicit and explicit memory (Schacter, Bowers, & Booker, 1989) it is not necessary in the present case given the pervasive effects of divided attention on explicit tests of all types (e.g., Mulligan, 1997, 1998; Mulligan & Hartman, 1996). In addition, recognition memory is a good choice for an explicit test in the present case because it is less sensitive to divided attention than many other explicit tests, such as free or cued recall (e.g., Craik et al., 1996). Consequently, recognition produces a conservative measure of the impact of divided attention on explicit memory, and dissociations between recognition and implicit tests are less likely to be produced by quantitative differences in sensitivity.

4. One might also consider percent correct on the distractor task, which is somewhat higher for the three-odd task than the odd-even task. However, this measure of "strength" is not directly comparable across tasks, and may reflect differences in task prioritizing induced by the two different distractor tasks.

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