Perceptual interference at encoding enhances recall for high- but not low-imageability words

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Interfering with stimulus perception during encoding can improve later explicit memory (the perceptual-interference effect). The compensatory-processing hypothesis attributes the perceptual-interference effect to enhanced processing of higher level (nonvisual) information during perception. Recent research indicates that the semantic dimension of imageability is one type of higher level information that plays a role in word perception. To the extent that semantic representations play a more important role in the perception of high- than for low-imageability words, the compensatory-processing hypothesis predicts a larger perceptual-interference effect for high- than for low-imageability words. Two experiments confirm this prediction. A robust effect of perceptual interference was found for high- but not for low-imageability words.

Interfering with perception during stimulus encoding can enhance later explicit memory (Hirshman & Mulligan, 1991; Nairne, 1988). The *perceptual-interference effect* is typically investigated in a study-test experimental paradigm in which study words are presented in one of two conditions. In the perceptual-interference condition, study words are presented on a computer screen very briefly (e.g., 100 msec) and then backward masked (e.g., with a row of "x"s). In the intact condition, study words are presented clearly (i.e., unmasked) on the computer screen for a few seconds (e.g., 2.5 sec). In both cases, the participant's task is to read the study words. Subsequently, the participants' memory for the words is tested. Surprisingly, memory has been found to be better for words in the perceptual-interference than in the intact condition on a variety of explicit tests, including free recall, recognition, and cued recall (see Mulligan, 1996, for a review).

This counterintuitive finding is important for several reasons. First, the perceptual-interference effect is at odds with traditional principles of memory encoding, which assume that encoding occurs in a limited-capacity processing channel (see, e.g., Atkinson & Shiffrin, 1968; Raaijmakers & Shiffrin, 1981; see Hirshman, Trembath, & Mulligan, 1994, for discussion). Processing of an additional visual stimulus (e.g., a mask) should draw encoding resources away from the target stimulus, reducing later memory for the target rather than enhancing it. Second, the perceptual-interference effect violates the traditional finding that memory improves as presentation duration increases (e.g., Roberts, 1972). Words in the perceptual-interference condition are presented for a fraction of the

duration of intact words and yet lead to better memory. Third, the effect may be inconsistent with the principle of transfer-appropriate processing (Morris, Bransford, & Franks, 1977), which predicts better memory performance as study and test conditions increase in similarity. It has been shown that even though all the test items on a recognition memory test are intact, the less similar perceptual-interference study condition leads to better memory (Westerman & Greene, in press). Finally, as argued below, the perceptual-interference effect illuminates aspects of the relationship between perception and memory.

Although perceptual interference affects recognition as well as free and cued recall (Hirshman & Mulligan, 1991; Hirshman et al., 1994; Mulligan, 1996; in press; Nairne, 1988; Westerman & Greene, in press), the phenomenon does have boundary conditions that place important limits on theorizing. First, it appears that perceptual interference improves performance only on conceptual explicit tests (see Roediger, 1990), such as recognition and free and cued recall. Perceptual interference does not improve performance on the conceptual implicit test of category-exemplar production (Mulligan, 1996), the perceptual implicit tests of perceptual identification (Hirshman & Mulligan, 1991) and speeded naming (Hirshman et al., 1994), or the perceptually explicit test of rhyme recognition (Mulligan, 1996). Second, although perceptual interference enhances recognition memory for the occurrence of an item, it does not enhance source memory for the encoding condition of the item (Mulligan, 1996). Third, perceptual interference reduces or leaves unaffected measures of interitem relational processing and memory for order (Mulligan, in press). Finally, the perceptual-interference effect does not occur for non-words or for very low frequency, unfamiliar words (Westerman & Greene, in press), indicating that the effect may depend on the lexical status of the study items.

Several potential accounts of the perceptual-interference effect have been investigated (e.g., differential rehearsal,

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elaborative encoding, demand characteristics, encoding effort, visual distinctiveness). Hirshman et al. (1994) and Mulligan (1996) concluded that the pattern of results just reviewed is consistent with only the compensatory-processing account.

Drawing on interactive-activation models of word perception (e.g., Masson, 1995; McClelland & Rumelhart, 1981; Seidenberg & McClelland, 1989), the compensatory-processing account suggests that the backward mask produces difficulties in the visual processing of perceptual-interference items, forcing participants to perform additional processing of higher level (nonvisual) information (such as phonology, meaning, and/or abstract lexical information). This additional processing of higher level information yields the subsequent mnemonic benefit (see Hirshman et al., 1994, and Mulligan, 1996, for discussion). The notion of compensatory processing has been used to account for the improved comprehension and memory stemming from reading inverted as opposed to standard text (see, e.g., Graf & Levy, 1984; Graf & Ryan, 1990; Masson & Sala, 1978), but in that case, the higher level processing was characterized as elaborative rehearsal (e.g., Graf & Ryan, 1990). Hirshman et al. (1994; see also Mulligan, 1996) argued that the higher level processing in the masking paradigm is perceptual rather than rehearsal based for several reasons. First, assuming that increasing total study time allows increased rehearsal, then, according to a rehearsal account, increasing study time should increase the size of the perceptual-interference effect. Contrary to this prediction, Hirshman et al. found that a considerable increase in study time did not increase the perceptual-interference effect in recognition or recall. Second, as noted, the category-exemplar production task, known to be sensitive to variation in elaborative rehearsal (see, e.g., Srinivas & Roediger, 1990), was unaffected by the perceptual-interference effect. Both of these findings argue against an elaborative rehearsal account of perceptual interference. Third, the perceptual-interference effect appears to arise during perception. The perceptual-interference effect is eliminated if the duration of the word-mask stimulus onset asynchrony (SOA) is increased to a point at which the mask no longer disrupts word identification (e.g., an SOA of 266 msec, Hirshman et al., 1994). Fourth, although the effect arises during word perception, the perceptual-interference effect does not occur on tests sensitive to variation in prior visual processing, like perceptual identification, word-stem completion, and speeded naming. Thus, the locus of the effect appears to be nonvisual. This account finds additional support in studies of word perception, which have demonstrated that phonological, lexical, and semantic information play a role in word perception (e.g., Balota, 1990; Masson, 1995; Seidenberg & McClelland, 1989; Strain, Patterson, & Seidenberg, 1995).

Earlier studies of the perceptual-interference effect have focused on (1) establishing the replicability and breadth of the effect (Hirshman & Mulligan, 1991; Mulligan,

1996, in press) or (2) testing (and eliminating) more conventional accounts of the effect (Hirshman & Mulligan, 1991; Hirshman et al., 1994; Mulligan, 1996). One way to test more directly the compensatory-processing account would be to identify an aspect of higher level information that plays a role in word perception and to examine its impact on the perceptual-interference effect. In a recent study, Strain et al. (1995) identified imageability as one semantic dimension affecting the speed and accuracy of word perception. High-imageability words (like *lamp* or *cloud*) have meanings that include many sensory properties, whereas low-imageability words (like *liberty* or *fact*) have meanings that are more abstract, with few concrete sensory properties. Strain et al. compared high- and low-imageability words, matched on a set of other variables known to influence word perception, and found that the high-imageability words were perceived more quickly and accurately. They concluded that semantic representations play a role in word perception and that such representations play a larger role in the perception of high- than in low-imageability words.

The compensatory-processing hypothesis attributes the perceptual-interference effect to the role of higher level (including semantic) information in perception. This suggests that the greater the role of such information, the larger the perceptual-interference effect should be. Consequently, this hypothesis predicts a larger perceptual-interference effect for high- than for low-imageability words. This prediction was tested in Experiment 1, in which high- and low-imageability words were presented at study in either the intact or perceptual-interference condition, followed by a free recall memory test. In addition, high-imageability (or concrete) verbal materials often lead to better explicit memory than low-imageability (or abstract) materials (the concreteness effect; see Paivio, 1991, for a review). However, this effect is typically small or nonexistent in free recall under conditions similar to those of the present experiment (see, e.g., Marschark & Surian, 1992; Nelson & Schreiber, 1992). Although not the focus of the present inquiry, this issue is addressed in later discussion.

EXPERIMENT 1

Method

Participants. Eighteen undergraduates at Illinois State University participated in exchange for extra credit in psychology courses.

Design and Materials. Encoding condition (intact vs. perceptual interference) and word imageability (high vs. low) were manipulated within subjects. The critical study items were a set of 32 low-frequency exception words developed by Strain et al. (1995, Appendix B). Exception words have inconsistent or unusual spelling-sound correspondences (e.g., *guise*). These materials were used because, of Strain et al.'s stimuli, the low-frequency exception words showed the largest imageability (i.e., semantic) effects in word perception. Strain et al. selected these items on the basis of imageability ratings from several published and unpublished sources (see Strain et al., p. 1141), all of which used a common 1 (*low imageability*) to 7 (*high imageability*) rating scale. The low-imageability items were chosen from the range 1–4.3, and the high-imageability items from the range 4.9–7. In addition, the items had Kučera and Francis (1967) values of below 30 per

million. Because Strain et al. were attempting to develop a set of words that varied only along the semantic dimension of imageability, pairs of high- and low-imageability items were matched as closely as possible on several other dimensions: Kučera–Francis (1967) word frequency, number of letters, initial phoneme or class of phonemes, and position bigram frequency (Solso & Juel, 1980). The resulting set of 16 high-imageability and 16 low-imageability words had the following mean values: imageability (high imageability = 5.74, low imageability = 3.52), frequency (high imageability = 6.50, low imageability = 5.60), number of letters (high imageability = 5.30, low imageability = 5.80), position bigram frequency (high imageability = 4,679.90, low imageability = 4,486.50).

The critical items were used to develop two study lists, across which imageability and encoding condition were factorially manipulated. Within each list, the words were randomly ordered subject to the restriction that no more than two consecutive words were of the same imageability type or encoding condition. Six additional low-frequency regular words were chosen from Strain et al.'s (1995) materials to serve as primacy (3) and recency (3) buffers, bringing the total list length to 38 words. Across participants, each critical word appeared equally often in the intact and perceptual-interference conditions.

Procedure. At the start of the experiment, participants were told that this was an experiment on word perception and that they would be presented with a series of words on a computer screen to read aloud. Participants were not informed of the impending memory test. They were told that some of the words would be presented very briefly and then covered with x's and that other words would be presented on the screen continuously for a couple of seconds. Participants were informed that each word would be preceded by a prompt consisting of the words "get ready" centered above a plus sign. They were told that the word would then be displayed in place of the plus sign. Participants were encouraged to focus their attention on the plus sign in order to maximize their chances of identifying the word. Study trials proceeded as described, beginning with the "get ready" prompt for .5 sec. After the prompt, the study word was displayed. In the perceptual-interference condition, the word was presented for 110 msec and then backward masked with a row of "x"s for 2,390 msec. In the intact condition, the word was displayed continuously for 2,500 msec. Participants read the words aloud while an experimenter recorded their responses.

A 3-min distractor task followed the study portion of the experiment. Participants were presented with a set of index cards, each containing the first three letters of a U.S. city (e.g., *Dal* for *Dallas*). They were asked to complete each stem with the name of a U.S. city. Following the distractor task, participants were presented with a blank sheet and asked to recall the words from the study list. Participants were encouraged to take their time and try to recall as many words as possible. No time limit was imposed.

Results and Discussion

Performance at study. For these and subsequent analyses, the significance level was set to .05. A studied word was considered nonidentified if the participant failed to say the word entirely, misidentified the word as a different word, or mispronounced the word.¹ Mean proportions of study words correctly identified are presented in Table 1. Because there was little variability in the intact relative to the interference condition, nonparametric sign tests were used. Identification was significantly lower in the perceptual-interference than in intact condition for both high- and low-imageability items. In addition, in the perceptual-interference condition, identification rates were significantly higher for high- than for low-imageability items [$F(1,42) = 27.27$, $MS_e = 0.0057$]. These results indicate that the perceptual-interference condition made word perception more difficult—differentially so for the low-imageability words. The latter out-

Table 1
Mean Proportion of Study Words Correctly Identified as a Function of Encoding Condition and Imageability

Imageability	Encoding Condition	
	Intact	Perceptual Interference
Experiment 1		
High	.99	.90
Low	.99	.84
Experiment 2: 110-msec word-mask SOA		
High	.99	.92
Low	.97	.83
Experiment 2: 130-msec word-mask SOA		
High	.99	.97
Low	.98	.91

Note—SOA, stimulus onset asynchrony.

come is consistent with the finding that low-imageability words take longer to identify (Strain et al., 1995). The test data were analyzed in two ways, conditionalized on identification at study and unconditionalized. Both analyses consistently led to the same conclusions. Only the conditionalized test data are reported below.

Performance at test. The proportions of study words recalled are presented in Table 2. An analysis of the recall proportions uncovered three significant effects: (1) a main effect of encoding condition, [$F(1,17) = 8.59$, $MS_e = 0.0176$] indicating greater recall in the perceptual-interference than in the intact condition; (2) a main effect of imageability, [$F(1,17) = 7.34$, $MS_e = 0.0082$], indicating greater recall for high- than for low-imageability words; and (3) an encoding condition $\times$ imageability interaction [$F(1,17) = 5.78$, $MS_e = 0.0135$], indicating that the effect of perceptual interference was larger for the high-imageability items. The perceptual-interference effect was significant for high-imageability words [$t(17) = 3.15$], but not for low-imageability words [$t(17) < 1.0$]. In addition, a significant effect of imageability was found in the perceptual-interference condition [$t(17) = 3.06$], but not in the intact condition [$t(17) < 1.0$].

The results are consistent with the prediction of the compensatory-processing hypothesis: The perceptual-

Table 2
Mean ($\pm$ SE) Proportion of Words Recalled as a Function of Encoding Condition and Imageability

Imageability	Encoding Condition			
	Intact		Perceptual Interference	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Experiment 1				
High	.09	.02	.25	.04
Low	.10	.02	.13	.02
Experiment 2: 110-msec word-mask SOA				
High	.08	.02	.20	.04
Low	.11	.03	.08	.03
Experiment 2: 130-msec word-mask SOA				
High	.12	.02	.21	.03
Low	.08	.02	.10	.02

interference manipulation interacted with imageability. Perceptual interference more than doubled recall of the high-imageability words but had no measurable effect on recall of the low-imageability words. A final interesting result, to be discussed after Experiment 2, is that a concreteness effect was found in the perceptual-interference condition but not in the intact condition.

Although consistent with the compensatory-processing hypothesis, the present results may not be totally conclusive. In particular, it may be problematic that identification rates at study were lower for the low- than for the high-imageability items. Prior research indicates that if the word-mask SOA is too brief, the perceptual-interference effect may not emerge in free recall (Hirshman & Mulligan, 1991; Nairne, 1988). It could be argued the 110-msec word-mask SOA is functionally too brief to elicit the perceptual-interference effect for low-imageability words, even though the same SOA elicits the effect with the more easily identified high-imageability words. One way to address this concern is to determine whether the results replicate using a longer word-mask SOA, one long enough to increase identification rates for low-imageability words to the level of those for high-imageability words. In addition, it was reasoned that it would be prudent to replicate Experiment 1 using the original word-mask SOA. In Experiment 2, word-mask SOA was varied between subjects so that words presented in the perceptual interference condition were presented for either 110 msec (as in Experiment 1) or 130 msec.

EXPERIMENT 2

Method

The method of Experiment 2 was identical to that of Experiment 1 with the following exceptions. First, 48 undergraduates participated. Second, word-mask SOA in the perceptual-interference condition was varied between subjects (110 vs. 130 msec). The 110-msec SOA condition was identical to that in Experiment 1. In the 130-msec SOA condition, the perceptual-interference study trials were modified so that the word was presented for 130 msec and the backward mask for 2,370 msec. Note that the total trial time was held constant.

Results

Performance at study. Study-word identification levels were significantly higher in the intact than in the perceptual-interference condition in all cases except the 130-msec SOA high-imageability condition, in which identification rates did not significantly differ (Table 1). Proportions of study words identified in the perceptual-interference conditions were also submitted to a 2×2 analysis of variance (ANOVA), using word imageability (high vs. low) as a within-subjects factor and word-mask SOA (110 vs. 130 msec) as a between-subjects factor. Not surprisingly, the main effect of word-mask SOA was significant [$F(1,46) = 5.27$, $MS_e = 0.0189$], indicating that the longer word-mask SOA increased identification. The main effect of imageability was also significant [$F(1,46) = 19.48$, $MS_e = 0.0078$], indicating, as in Exper-

iment 1, greater identification in the high- than in the low-imageability condition. The interaction was not significant. The results again indicate that backward masking in the perceptual-interference condition disrupts perception and, again, differentially so for the low-imageability words. More important, when the word-mask SOA was increased to 130 msec, identification in the low-imageability condition was approximately equal to the identification levels of the high-imageability words presented at an SOA of 110 msec.

Performance at test. The proportions of study words recalled are presented in Table 2. The results replicate and clarify the results of Experiment 1. Specifically, perceptual interference enhanced recall for the high- but not for the low-imageability items, even when the word-mask SOA was lengthened to 130 msec. Recall proportions were analyzed with a $2 \times 2 \times 2$ ANOVA, using encoding condition and word imageability as within-subjects factors and word-mask SOA as a between-subjects factor. Three significant effects were revealed: (1) a main effect of encoding condition [$F(1,46) = 8.59$, $MS_e = 0.0147$]; (2) a main effect of imageability, [$F(1,46) = 16.40$, $MS_e = 0.0106$]; and (3) an encoding condition $\times$ imageability interaction [$F(1,42) = 7.54$, $MS_e = 0.0174$], indicating that the effect of perceptual interference was larger for the high-imageability items. No other effects were significant ($ps > .25$).

To investigate the encoding condition $\times$ imageability interaction, the data from the high- and low-imageability conditions were analyzed with separate 2 (encoding condition) $\times$ 2 (word-mask SOA) ANOVAs. The perceptual-interference effect was significant for the high-imageability items [$F(1,46) = 13.85$, $MS_e = 0.0187$], but not for the low-imageability items ($F < 1.0$). No other effects were significant in either analysis ($ps > .25$). In addition, the data from the intact and perceptual-interference conditions were submitted to separate 2 (imageability) $\times$ 2 (word-mask SOA) ANOVAs. These analyses revealed an effect of imageability in the perceptual-interference condition [$F(1,46) = 16.58$, $MS_e = 0.0185$], but not in the intact condition ($F < 1.0$). No other effects were significant in either analysis ($ps > .10$).

The 110-msec condition provided a direct replication of Experiment 1. Consistent with the compensatory-processing account, the effects of perceptual-interference were greater when semantic information played a greater role in perception (i.e., the high-imageability condition). Also replicating Experiment 1, the perceptual-interference effect was eliminated in the low-imageability condition. The same pattern of results was found in the 130-msec condition. Importantly, study performance for the low-imageability items in this condition was comparable to study performance in the high-imageability condition with a word-mask SOA of 110 msec. This indicates that the null perceptual-interference effect for the low-imageability items was probably not due to a presentation duration that was too brief. Even when the high- and low-imageability

items were equated on study identification (i.e., comparing high-imageability items at an SOA of 110 msec with the low-imageability items at an SOA of 130 msec), it was found that perceptual interference enhanced recall for the high- but not for the low-imageability items.

Although the compensatory-processing hypothesis predicts the encoding condition $\times$ imageability interaction, it did not explicitly predict a null effect of encoding condition in the low-imageability condition. Because this null effect may be theoretically meaningful, it is important to consider the statistical power of this comparison. The low-imageability data from Experiments 1 and 2 were combined to yield a more powerful test of encoding condition. As might be expected, mean recall in the intact and the perceptual-interference conditions did not significantly differ (.09 and .10, respectively; $F < 1.0$). In the combined data set, the effect size of encoding condition for the high-imageability condition was $d = .86$. The power to detect an effect of this size in the low-imageability condition exceeds .99 ($\alpha = .05$, one-tailed, $N = 66$). The power to detect an effect one half this size is .80. Thus, there was considerable power to detect an effect of perceptual interference if it existed in the low-imageability condition.

One final consideration is that recall in the low-imageability condition was somewhat low (around 10%), raising the possibility that the perceptual-interference effect in this condition was obscured by a floor effect (and that the encoding condition $\times$ imagery interaction was artifactual). An analysis of the top third of the participants (in terms of overall recall) from Experiments 1 and 2 argues against this interpretation. This analysis revealed a significant encoding condition $\times$ imagery interaction [$F(1,21) = 7.60$, $MS_e = 0.0219$], in which perceptual-interference significantly increased recall in the high-imageability [.16 vs. .35; intact and perceptual interference, respectively; $t(21) = 4.33$] but not in the low-imageability (.15 vs. .16; intact and perceptual interference, respectively; $t(21) < 1.0$] condition. An analysis of the top third of the participants in terms of low-imageability recall also revealed no trend toward a perceptual-interference effect in the low-imageability condition [.18 vs. .19; intact and perceptual interference, respectively; $t(21) < 1.0$].

GENERAL DISCUSSION

Experiments 1 and 2 yielded consistent results: The perceptual-interference effect occurred for high- but not for low-imageability words. This supports the compensatory-processing account, which predicts that the size of the perceptual-interference effect is mediated by higher level (including semantic) information in perception. To the extent that higher level semantic information plays a larger role in the perception of high- than of low-imageability words (Strain et al., 1995), the compensatory-processing account predicts a greater perceptual-interference effect for high- than for low-imageability words. In addition, these results are consistent with the recent results of Westerman and Greene (in press), who reported that the perceptual-interference effect is not obtained with nonwords or unfamiliar low-frequency words. Presumably, these stimuli lack the higher level semantic representations that contribute to the perceptual-interference effect.

Finally, a brief discussion of the concreteness effect is in order. A concreteness effect was obtained in the perceptual-interference condition but not the intact condition. On the basis of prior research, the null effect in the intact condition is not surprising. In free recall, the effects of concreteness seem to emerge when encoding conditions encourage interitem associations or relational encoding, which can be fostered by presenting the study list multiple times or using intentional encoding instructions (e.g., Marschark & Surian, 1992; Nelson & Schreiber, 1992). The present study used incidental learning instructions, the study list was presented only once, and the encoding circumstances focused participants' attention on isolated items, thus discouraging interitem associative rehearsal. Concreteness effects are minimized or eliminated in free recall under these conditions (Marschark & Hunt, 1989; Marschark & Surian, 1992; Nelson & Schreiber, 1992; see Marschark & Hunt, 1989, p. 718, for discussion).

In this light, the surprising finding is that the perceptual-interference manipulation induced a concreteness effect under conditions in which it does not usually occur. As reviewed earlier, the locus of the perceptual-interference effect appears to be in higher level perceptual processing. The present study lends credence to the notion that this higher level perceptual information includes semantic information active during perception. This implies that a concreteness effect may be induced by perceptual processing during word perception. Although a complete discussion of accounts of the concreteness effect is beyond the scope of this article, several of the extant accounts suggest that concreteness effects are the result of strategic (and postperceptual) rehearsal processes (see Nelson & Schreiber, 1992, for a review). The present results imply that there may be a basis of concreteness effects that arises during word perception, due to the automatic activation of semantic or imaginal information. For this account to dovetail with the compensatory-processing hypothesis, such semantic or imaginal information must play a role in word perception. Consequently, the effects of this mnemonic information may be quite different from the effects of postperceptual elaborative rehearsal.

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NOTES

1. A less stringent standard included mispronounced words as correctly identified. The pattern of results of these and subsequent analyses was unchanged.

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