Mechanisms of facilitation in primed perceptual identification

MARK TIPPENS REINITZ and REBECCA ALEXANDER
Boston University, Boston, Massachusetts

We investigated the mechanism that produces priming in perceptual identification. In Experiment 1, subjects studied a series of compound words (e.g., OUTDOOR, SIDELINE); in Experiment 2, subjects studied a series of pictures (photographs) of objects. All subjects later received perceptual identification tests in which old (primed) and new (unprimed) words (Experiment 1) or pictures (Experiment 2) were presented for varying durations and masked. In both experiments, performance for primed and unprimed stimuli was predicted essentially perfectly by a model that assumes that prior exposure to a stimulus results in increased visual information-acquisition rate when it is subsequently encountered. An ancillary purpose of Experiment 1 was to test whether or not priming occurs for recombined words (e.g., OUTLINE); there was no evidence for such priming at any exposure duration.

In perceptual identification (PID) tests, subjects attempt to identify masked, briefly presented stimuli. Performance in PID is typically better for previously presented stimuli than for new stimuli. This priming effect occurs for both words (e.g., Jacoby & Hayman, 1987; Reinitz & Demb, 1994) and pictures (e.g., Warren & Morton, 1982). Substantial evidence indicates that priming in PID represents an automatic effect of memory on perceptual processing. For example, findings showing that the priming effect is independent of recognition memory performance (e.g., Jacoby & Dallas, 1981) and occurs in both normal and amnesic subjects (e.g., Cermak, Talbot, Chandler, & Wolbarst, 1985) indicate that the effect is automatic rather than intentional. Various findings indicate that the effect is perceptual rather than postperceptual. For instance, recent PET studies of perceptual priming have found changes in blood flow in area 18 of the occipital cortex for primed stimuli relative to unprimed stimuli (Schacter, 1994; Squire et al., 1992). Schacter (1994) failed to find blood-flow changes resulting from priming in any brain region other than the occipital cortex, consistent with the proposal that the priming effect is primarily perceptual. Additionally, PID performance is influenced by perceptual manipulations, such as changing the font from study to test (e.g., Jacoby & Hayman, 1987), but not by conceptual manipulations, such as depth of processing (e.g., Challis & Brodbeck, 1992) or intermodal priming (e.g., Weldon, 1991).

All of these findings indicate that visual perceptual processing is facilitated by prior exposure to stimuli. However, PID studies typically have been designed to study proper-

ties of implicit memory rather than to study perceptual effects per se; as a result, very little research has directly addressed the issue of how prior stimulus exposure facilitates perception. The purpose of our research was to test between two simple explanations of how prior stimulus exposure produces perceptual facilitation. By an *additive* model, prior stimulus exposure reduces the amount of information that must be acquired from a test stimulus in order to identify it. By a *multiplicative* model, visual information is acquired more rapidly from primed stimuli than from unprimed stimuli. We discuss each of these models in turn.

Additive and Multiplicative Models of Priming in PID

By an additive model, less information must be acquired from primed stimuli than from unprimed stimuli in order to identify them. For example, Ratcliff, Hockley, and McKoon (1985) and Warren and Morton (1982) proposed that stimulus identification occurs when some unit or set of units in memory becomes sufficiently activated. To explain the sort of implicit priming that occurs in PID, these authors proposed that exposure to a stimulus produces prolonged increased activation of these units, so that, for some period of time, the amount of activation required from the stimulus in order to identify it is reduced relative to the amount of activation required from unprimed stimuli. In this case, some activation that would normally be required from the stimulus has already been provided by the prime. By this explanation, priming provides information that otherwise would have to be acquired from the stimulus during the first k milliseconds of its exposure; priming is therefore equivalent to a k -millisecond preexposure of the stimulus.

By a multiplicative model, prior stimulus exposure increases the efficiency of perceptual encoding such that visual information is acquired more rapidly from primed stimuli than from unprimed stimuli. We do not know of any published examples of multiplicative models of priming in PID. However, several considerations indicate that

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such a model is worth testing. First, a variety of manipulations have been shown to affect rate of visual encoding. These include perceptual manipulations, such as luminance (e.g., Loftus, 1985; Loftus & Ruthruff, 1994), and cognitive manipulations, such as focused attention (e.g., Reinitz, 1990; Stelmach, Herdman, & McNeil, 1994). Most relevant to PID is the finding that visual information is acquired more rapidly from a briefly presented picture if it is immediately preceded by its category name (i.e., if it is semantically primed) than if it is not primed (Reinitz, Wright, & Loftus, 1989). Semantic priming effects are clearly different from the sort of priming observed in PID; for instance, semantic priming effects persist for only a few seconds, whereas priming in PID persists for hours or even days. Additionally, strong semantic priming effects occur cross-modally (i.e., when the prime is a word and the target is a picture); priming in PID does not occur cross-modally. Nonetheless, Reinitz et al. (1989) demonstrated that memory can exert an effect on perception that is characterized by an increase in visual encoding rate. Priming in PID also represents an example of an effect of memory on perception; this effect might also be characterized by increased encoding efficiency.

Experimental Paradigm and Analytical Strategy

In the experiments that we report, subjects first studied a series of stimuli. They later received a PID test in which old (previously studied) and new (unstudied) stimuli were presented for varying brief durations and masked; the task was to identify the stimuli. These experiments made it possible to generate functions relating performance to exposure duration for the two conditions; we refer to these functions as *performance curves*.

Performance curves are typically curvilinear when proportion correct is used as the performance measure. In order to simplify the analysis, it will be useful to transform the performance curves to obtain linear functions. This can be done by fitting the performance curves to the exponential equation,

$$P = \begin{cases} 0 & \text{for } d \leq L \\ 1.0 - e^{-(d-L)/c} & \text{for } d > L \end{cases}, \quad (1)$$

where d refers to stimulus duration, and L and c are free parameters. First, L refers to the x -intercept of the performance curve—that is, the duration above which performance is no longer at chance. Second, c is the duration exceeding L required to reach a criterion performance level of $p = 1.0 - 1/e$. Loftus, Busey, and Senders (1993), Loftus and Ruthruff (1994), and others have shown that this equation almost perfectly describes performance curves.

To obtain linear performance curves, we define a new dependent variable, $P = -\ln(1.0 - p)$. Equation 1 implies that P should be a linear function of d . That is, given Equation 1,

$$P = \begin{cases} 0 & \text{for } d \leq L \\ (1/c)d - L/c & \text{for } d > L \end{cases}. \quad (2)$$

P is therefore linearly related to duration with a slope of $1/c$ and a y -intercept of L/c .

If Equation 1 provides a good fit to our experimentally obtained performance curves, it will therefore be possible to transform them to linear functions. Linear regression can then be used to test the goodness of the linear fits and to estimate the values of the model parameters c and L . This is convenient, since the additive and multiplicative models make different predictions regarding these parameters, which we describe below.

First, consider the additive model. As described in the previous section, additive models propose that priming is equivalent to a k -millisecond preexposure of the stimulus. Thus, any performance level reached following a d -millisecond primed presentation will require a $d+k$ millisecond unprimed presentation; in other words, primed and unprimed performance curves should be separated across their entire shared range by a k -millisecond constant. This, of course, implies that performance curves for the two conditions will have identical slopes (or, in terms of our model parameters, that the linear trends for the two conditions will produce equal estimates of c). Horizontally displaced linear functions of equal slope must have different x -intercepts; an additional prediction, therefore, is that the two conditions will produce different estimates of L . The additive model predictions are shown in the top panel of Figure 1.

Multiplicative models propose that information is encoded more rapidly from primed stimuli than from unprimed stimuli by some constant factor, C . This predicts that primed and unprimed performance curves will differ in slope (i.e., will produce different estimates of c). Consider, for instance, the proposal that information is acquired twice as rapidly from primed stimuli as from unprimed stimuli (i.e., $C = 2$). Assuming that equal performance implies equal information, then as duration increases, performance will increase twice as rapidly in the primed condition as in the unprimed condition—that is, the ratio of the slopes will be 2:1.

Different multiplicative models are possible that make different predictions regarding the relative values of L for a primed condition and an unprimed condition. Consider first a model in which acquisition of information that is useful for stimulus identification does not commence at stimulus onset but rather begins following L milliseconds of stimulus exposure. By such a model, it is assumed that L milliseconds of stimulus exposure are required for processes that are preparatory to information acquisition and that are unaffected by the priming manipulation. For instance, Busey and Loftus (1994) and Loftus and Ruthruff (1994) proposed that the strength of the sensory response to a stimulus increases with increasing exposure duration and that information extraction requires a sensory response that is greater than some sensory threshold. Thus, information acquisition does not commence at stimulus onset but rather begins following some duration, L , which is required for the sensory response to rise above threshold. Since the strength of the sensory response is assumed to

Figure 1. Model predictions when performance is measured in $P = -\ln(1.0 - p)$. The top panel shows the additive predictions of equal slopes and differing x-intercepts. The middle panel shows the multiplicative predictions when acquisition of task-useful information commences following L milliseconds of stimulus exposure. The bottom panel shows the multiplicative predictions when information acquisition begins at stimulus onset.

depend solely on stimulus factors (such as luminance), L should be equal for primed and unprimed stimuli. If it is assumed that performance rises above chance at the point when task-relevant information becomes available from the stimulus, then this multiplicative model predicts equal x-intercepts for primed and unprimed performance curves. This prediction is presented in the middle panel of Figure 1.

Consider an alternative multiplicative model of information acquisition, by which visual encoding begins at stimulus onset. If the x-intercept is not 0, then it is necessary to assume that some criterion amount of information (I_{cr}) must be acquired from a test stimulus before performance rises above chance. Multiplicative models propose

that information is acquired more rapidly from primed stimuli than from unprimed stimuli; therefore I_{cr} will be acquired at a briefer exposure duration (i.e., L will be smaller) for primed stimuli than for unprimed stimuli. These predictions are shown in the bottom panel of Figure 1.

EXPERIMENT 1

The purpose of Experiment 1 was to test between additive and multiplicative models of priming in PID for words. Subjects studied a series of compound words (e.g., HORSEFLY, TOOTHPASTE, SNOWSHOE, etc.) and categorized each word as a noun, a verb, or an adjective. They were not told to expect a memory test. Subjects later received a PID test in which stimuli were presented for varying brief durations and masked. There were four types of test words: *old* words, which had been previously studied; *new* words, which had not been studied; *conjunction* words, which were new words constructed by recombining parts of previously studied words (e.g., HORSESHOE); and *feature* words, each of which contained one old and one new part (e.g., TOOTHACHE). The latter two types of test words were included in order to provide a replication of Reinitz and Demb's (1994) recent failure to find priming in PID for conjunction words. Those authors demonstrated that subjects who received a recognition test for compound words made many more false alarms to conjunction words than to feature or new words, indicating that the memories that underlie recognition performance are composed of parts that can be independently activated. However, in PID, there was priming for old words but not for conjunction words. Perceptual effects of prior stimulus exposure therefore appear to require a holistic match between the study and test stimuli.

Method

Subjects. The subjects were 120 Boston University undergraduate students who participated for credit in their introductory psychology classes. They were run in forty 3-subject groups.

Stimulus and Apparatus. The study and test stimuli were photographic slides of 120 compound words. Eighty were paired so that the first segment of the first word in the pair and the second segment of the second word in the pair made a novel compound word when combined (e.g., OVERSIGHT, RAINCOAT, OVERCOAT). This resulted in 40 additional conjunction words. An additional 5 words were used for practice; these were unrelated to any of the study or test words. Stimuli subtended about 7° of visual angle horizontally and about 0.75° vertically. A noise mask consisted of a slide containing a jumble of straight and curved black lines; it subtended about 10° vertically and about 15° horizontally. The luminances were such that when the mask and a word were presented simultaneously, the word could not be seen. All stimuli were presented using Kodak slide projectors equipped with Gerbrands tachistoscopic shutters. The projectors and shutters were controlled by an IBM-AT-compatible computer, and timing was controlled by a clock card in the computer.

Design and Procedure. The subjects were told that they were participating in a test of grammatical knowledge. They saw a series of 40 compound words, presented for 3 sec each. During the 4-sec interstimulus interval, the subjects circled each word's part of speech on their response sheets.

Following the study phase, the subjects completed a mental rotations test. This filler task took about 15 min.

Finally, the subjects received a PID test. They received 40 experimental trials, which were preceded by 5 practice trials. They attempted

to identify each word and wrote down their responses on an answer sheet. Words were presented for 40, 65, 90, 115, and 140 msec and were immediately followed by the mask, which was presented for 9 sec in order to provide sufficient light for the subjects to write down their responses. Ten (old) words had been presented during the study phase, and 10 (new) words had not been previously presented. Additionally, 10 of the words were conjunction stimuli, and 10 were feature stimuli. For 5 of the feature stimuli presented to a given group, the first segment of each word was novel; for the other 5, the second segment of each word was novel. No word segment was used in more than one test word. The four priming conditions were factorially combined with the 5 exposure durations to produce 20 test conditions. Across the 40 groups, each word occurred in each test condition twice. Additionally, when used as a feature stimulus, each test word contained the first segment of a previously studied word and the last segment of a previously studied word equally often. All of the groups received the identical test stimuli in the identical order. The groups, of course, received different study stimuli; the presentation order of study stimuli was random for each group.

Results and Discussion

Preliminary analysis. Figure 2 shows proportion correct as a function of exposure duration for the four test

Figure 2. Performance curves for the four priming conditions. Proportion correct is plotted as a function of exposure duration; error bars indicate the standard errors.

Figure 3. Experiment 1: Primed and unprimed performance curves. Identification performance is measured in $P = -\ln(1.0 - p)$. Solid lines show the best-fitting regression lines. Error bars indicate the 95% confidence intervals.

Table 1
Estimates (in Milliseconds) of the Model Parameters c and L for the Two Priming Conditions in Experiment 1

Condition	Parameter	
	$c = 1/\text{slope}$	L
Estimates From Group Data		
Primed	62.612	34.332
Unprimed	88.387	33.221
Estimates Based on 20 Metagroups		
Primed	50.465 ± 9.518	24.098 ± 4.737
Unprimed	74.325 ± 11.037	21.635 ± 7.383

Note—95% confidence intervals are shown for metagroup data.

conditions. Error bars indicate the standard errors for the various conditions. It is obvious from the figure that priming occurred only for old stimuli. The results therefore demonstrate the generality of Reinitz and Demb's (1994) finding of no priming for conjunction stimuli across a wide range of exposure durations. Since there was no evidence for any differences between the conjunction, feature, and new conditions, data from these conditions have been pooled in all of the subsequent analyses to produce a single unprimed performance curve that provides the most stable possible estimate of unprimed performance.

Test of additive and multiplicative models. Figure 3 shows the primed and unprimed performance curves; performance has been plotted as a function of our transformed dependent variable P . The error bars show the 95% confidence intervals, and the solid lines show the best-fitting regression lines. The linear fits are essentially perfect (r^2 s = .993 and .997 for the primed and unprimed conditions, respectively).

Recall that the additive model predicts that performance curves will have equal slopes and differing x -intercepts and that multiplicative models predict that the curves will differ in slope. Estimates of the model parameters c and L derived from the group data are presented in Table 1. Consistent with the multiplicative model, the slopes differ substantially. In addition, the x -intercepts are nearly identical, as predicted by a model in which information acquisition commences following some preparatory period of stimulus exposure.

To obtain measures of the variability of our parameter estimates, we decided to estimate the parameter values separately for groups. There were only 6 trials per group in each condition. As a result, there were 19 groups for which performance was perfect in at least one condition. The dependent variable P is undefined for cells in which proportion correct equals 1.0. We therefore constructed "metagroups" in which data from paired groups were pooled. Groups were paired randomly with the constraint that proportion correct was less than 1.0 for all conditions in the resulting metagroup. The means of the resulting parameter estimates and their 95% confidence intervals are also presented in Table 1. The data confirm our previous assertion: the estimates of c for the two conditions are quite different and their confidence intervals do not overlap, and the estimates of L are quite similar. The effect of prior expo-

Figure 4. Experiment 2: Primed and unprimed performance curves. Identification performance is measured in $P = -\ln(1.0 - p)$. Solid lines show the best-fitting regression lines; error bars indicate the 95% confidence intervals.

sure to a word is to increase the rate at which it is encoded when it is subsequently encountered. Calculated from the group data, the factor by which priming increases encoding rate (indicated by the ratio of the slopes of the primed and unprimed conditions) is 1.41.

EXPERIMENT 2

Experiment 2 tested whether the effects observed for word stimuli in Experiment 1 generalized to picture stimuli. Priming in PID has been demonstrated for both words and pictures. Many authors have demonstrated that post-perceptual processing proceeds quite differently for pictures and words (e.g., Loftus, 1982; Potter & Faulconer, 1975). However, there is no reason to suspect that the basic perceptual processes involved in visual encoding should differ between the two stimulus types. We propose that priming in PID represents an effect on such processes; we therefore predict priming should exert identical effects on pictures and words. On the basis of the results of Experiment 1, we predict that picture priming will be well described by a multiplicative model.

Method

Subjects. The subjects were 60 Boston University undergraduate students who participated for credit in their introductory psychology classes. They were run in twenty 3-subject groups.

Stimulus and Apparatus. Sixty color slides of common objects on gray backgrounds served as experimental stimuli. Five additional objects served as practice stimuli. Objects subtended from about 3° to about 9° both vertically and horizontally depending on the shape of the object. The mask used in Experiment 1 was again used here. Luminances were such that when the mask and an object were presented simultaneously, it was impossible to identify the object. Stimuli were presented using the same apparatus that was used in Experiment 1.

Design and Procedure. The subjects were told that they were participating in a size-judgment task. At the start of the experiment, the subjects were shown a cardboard box measuring $8.5 \times 12 \times 14$ in. They were told that they would see a series of objects presented on the screen and that they would have to judge whether or not each object would fit in the box. The subjects then saw a series of 30 pictures, presented for 3 sec each. During the 4-sec interstimulus inter-

val, they indicated their size judgments by circling Ys and Ns on their answer sheets. The box was not present in the room during the study phase.

Following the study phase, the subjects completed a vocabulary test. This filler task took 15 min.

Finally, the subjects received a PID test. They received 60 experimental trials, which were preceded by 5 practice trials. Pictures were presented for 30, 50, 70, 90, and 110 msec and were immediately followed by the mask. The subjects attempted to identify them and wrote down the names of the objects on their response sheets. Thirty test pictures were old, and 30 were new. Six pictures were presented in each of the 10 conditions defined by factorially combining the 5 exposure durations with the two priming conditions. All of the subjects received the identical test stimuli in the identical order. Across groups, all of the pictures occurred in all of the conditions equally often.

Results and Discussion

Figure 4 shows the primed and unprimed performance curves; performance has been plotted as a function of our transformed dependent variable P . The error bars show the 95% confidence intervals, and the solid lines show the best-fitting regression lines. As in Experiment 1, the linear fits are essentially perfect (r^2 s = .998 and .987 for the primed and unprimed conditions, respectively).

Estimates of the model parameters c and L derived from the group data are presented in Table 2. The pattern is similar to the pattern obtained for word stimuli in Experiment 1: the x -intercepts of the curves are nearly identical, and the slopes differ substantially.

There were 18 trials per condition per group. No group performed perfectly in any condition; we were therefore able to obtain estimates of the parameter values for each group. The means of the resulting parameter estimates and their 95% confidence intervals are also presented in Table 2. As in Experiment 1, the data confirm the multiplicative model: the estimates of c for the two conditions are quite different, and the estimates of L are quite similar. Standard errors were substantially higher in the unprimed condition than in the primed condition. An examination of the individual-group data indicated that the value of c for one group was more than twice as large as the value obtained for any other group. This group was subsequently treated as an outlier; the resulting parameter es-

Table 2
Estimates (in Milliseconds) of the Model Parameters c and L
for the Two Priming Conditions in Experiment 2

Condition	Parameter	
	$c = 1/\text{slope}$	L
Estimates From Group Data		
Primed	59.049	15.055
Unprimed	93.357	15.359
Estimates Based on 20 Groups		
Primed	61.455 ± 9.745	12.855 ± 6.923
Unprimed	110.563 ± 35.447	9.235 ± 11.503
Estimates Based on 19 Groups (Outlier Removed)		
Primed	60.950 ± 10.219	13.262 ± 7.248
Unprimed	94.238 ± 16.076	14.009 ± 7.054

Note—95% confidence intervals are shown for the estimates based on 20 and 19 groups.

timates and their 95% confidence intervals are also presented in Table 2. The data provide an excellent fit to the multiplicative model and disconfirm the additive model. The factor by which priming increased encoding rate is 1.58.

GENERAL DISCUSSION

Summary

Additive models of priming in PID propose that priming reduces the amount of perceptual information that must be acquired from stimuli in order to identify them; they predict primed and unprimed performance curves with equal slopes and differing duration intercepts. These predictions were disconfirmed for both picture and word stimuli. Multiplicative models propose that visual information is acquired more rapidly from old stimuli than from new stimuli. They predict that performance curves for the two conditions will have different slopes; this prediction was confirmed for both stimulus types. The implication is that priming in PID is the result of more efficient information acquisition from old stimuli than from new stimuli. Furthermore, in each experiment, primed and unprimed performance curves had identical x -intercepts. This indicates that information acquisition does not begin at stimulus onset. Rather, L milliseconds of preparatory exposure is required before information acquisition begins. Our findings are therefore consistent with recent models of information acquisition proposed by Busey and Loftus (1994) and by Loftus and Ruthruff (1994), in which the strength of the sensory response increases with increasing exposure duration and in which information acquisition begins when the strength of the sensory response rises above some threshold.

Perceptual Versus Postperceptual Explanations

We argue that the specific effect of priming in our experiments was on perception. It might alternatively be proposed that the priming we observed was due to some postperceptual process. However, we prefer a perceptual explanation, for the following reasons. First, identical effects were observed for picture and word stimuli. This would be expected if the effects were on early perceptual processes, but not if they were on postperceptual processes.

Second, we have reviewed substantial experimental evidence that indicates that priming in PID represents a perceptual effect. In this regard, we note that several authors have demonstrated that PID is relatively invulnerable to strategies based in explicit recollection; such strategies are far more likely to be used in other types of implicit tasks, such as word-fragment completion (e.g., Challis & Brodbeck, 1992). Additionally, Reinitz and Demb (1994) specifically tested the possibility that intentional explicit recollection influenced the pattern of performance that they observed in their PID task, and they failed to find any evidence for an effect of intentional recollection. Specifically, removing old stimuli from the test and warning subjects to avoid naming old stimuli as responses had no effect on the means in the remaining conditions. Since

Experiment 1 used the same stimulus set, the same subject pool, and the same task as those authors used, it is unlikely that subjects employed a recollection-based strategy here.

Third, the proposal that prior exposure increases encoding rate leads to highly specific predictions that were empirically confirmed. There is no current postperceptual model of priming effects that predicts the multiplicative relation that we found.

Finally, our results are consistent with other findings regarding the specific effect of memory on perception. Reinitz et al. (1989) demonstrated that information is perceptually encoded more rapidly from semantically primed stimuli than from unprimed stimuli. Their effect must have been based in memory, since the relationship between the primes (words) and targets (pictures) in their study was conceptual. Additionally, their effect was probably implicit, in that the primes automatically produced perceptual facilitation. Our present result leads to the parsimonious proposal that, across a variety of manipulations, memory can exert an automatic effect on perception that is characterized by increased processing efficiency.

Applications of the Analytical Strategy

A widespread problem in contemporary priming research concerns the way in which priming benefit is measured. Experiments are often performed that are intended to compare the amount of priming that occurs between different experimental conditions (e.g., different encoding conditions) or between different populations of subjects (e.g., amnesics and controls). Priming is typically measured as the difference in performance between a primed condition and an unprimed condition; that is, amount of priming = $p(\text{primed}) - p(\text{unprimed})$. This procedure becomes problematic when overall performance is not equal across conditions or populations. In such cases, it is necessary to assume that the performance scale is linearly related to the underlying variable of interest (e.g., amount of information) in order for amount-of-priming comparisons to be meaningful. There is no a priori reason to expect that performance is a linear function of the construct being measured. For instance, it is perfectly plausible that a small increase in available information may produce a large increase in performance at low overall levels of performance and that the same increase in available information will produce only a modest performance increase at higher overall performance levels.

We feel that an important contribution of our work is that we provide a way to measure priming benefit that does not make strong assumptions regarding the performance scale. Specifically, we define priming benefit as the ratio of the slopes of the primed and unprimed performance curves—that is, as the factor by which priming increases encoding rate. Since linear trends can be estimated across a wide range of performance levels, it is not necessary that two groups display equal overall performance in order to test the proposal of equal priming across the groups. Our technique can therefore be applied to make assumption-free tests of priming differences in cases where overall performance levels differ.

Final Comments

Context (i.e., semantic priming) and prior exposure (i.e., priming in PID) both enhance perceptual efficiency; specifically, both increase the rate at which perceptual information is encoded from stimuli. Although the specific manipulations differ, both types of priming constitute cases in which the prior presentation of stimulus-relevant information leads to more efficient perceptual encoding. Other types of precues also facilitate perception. For instance, detection performance is facilitated by prior knowledge of spatial frequency (Davis, Kramer, & Graham, 1983), color (Humphreys, 1981), and form (Teichner & Krebs, 1974). These effects can also be taken as examples of memory effects on perception.

How might memory exert these effects? One possibility is that memory influences the allocation of visual attention to a stimulus. Several authors have recently demonstrated that visual attention specifically affects perceptual encoding rate. For instance, Reinitz (1990) showed that a multiplicative model accounted perfectly for differences in discrimination performance between validly cued (attended) and invalidly cued (unattended) stimuli. Using a different methodology, Stelmach et al. (1994) showed that the apparent motion produced by alternating attended and unattended stimuli was perfectly predicted by a model whose central feature was an encoding-rate difference resulting from attention. These findings raise the possibility that memory affects perception by focusing attention on task-relevant stimulus information, thereby increasing the rate at which this information is encoded. Research to test this possibility is currently under way.

REFERENCES

- BUSEY, T. A., & LOFTUS, G. R. (1994). Sensory and cognitive components of visual information acquisition. *Psychological Review*, **101**, 446-469.
- CERMAK, L. S., TALBOT, N., CHANDLER, K., & WOLBARST, L. R. (1985). The perceptual priming phenomenon in amnesia. *Neuropsychologia*, **23**, 615-622.
- CHALLIS, B., & BRODBECK, D. (1992). Levels of processing affect priming in word fragment completion. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **18**, 595-607.
- DAVIS, E. T., KRAMER, P., & GRAHAM, N. (1983). Uncertainty about spatial frequency, spatial position, or contrast of visual patterns. *Perception & Psychophysics*, **33**, 20-28.
- HUMPHREYS, G. W. (1981). Flexibility of attention between stimulus dimensions. *Perception & Psychophysics*, **30**, 291-302.
- JACOBY, L. L., & DALLAS, M. (1981). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General*, **110**, 306-340.
- JACOBY, L. L., & HAYMAN, C. A. G. (1987). Specific visual transfer in word identification. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **13**, 456-463.
- LOFTUS, G. R. (1982). Eye fixations on text and scenes. In K. Rayner (Ed.), *Eye movements and reading: Perceptual and language processes* (pp. 359-376). New York: Academic Press.
- LOFTUS, G. R. (1985). Picture perception: Effects of luminance on available information and information-extraction rate. *Journal of Experimental Psychology: General*, **114**, 342-356.
- LOFTUS, G. R., BUSEY, T. A., & SENDERS, J. W. (1993). Providing a sensory basis for models of visual information acquisition. *Perception & Psychophysics*, **54**, 535-554.
- LOFTUS, G. R., & RUTHRUFF, E. (1994). A theory of visual information acquisition and visual memory with special application to intensity-duration tradeoffs. *Journal of Experimental Psychology: Human Perception & Performance*, **20**, 33-50.
- POTTER, M. C., & FAULCONER, B. A. (1975). Time to understand pictures and words. *Nature*, **253**, 437-438.
- RATCLIFF, R., HOCKLEY, W., & MCKOON, G. (1985). Components of activation: Repetition and priming effects in lexical decision and recognition. *Journal of Experimental Psychology: General*, **114**, 435-450.
- REINITZ, M. T. (1990). Effects of spatially directed attention on visual encoding. *Perception & Psychophysics*, **47**, 497-505.
- REINITZ, M. T., & DEMB, J. B. (1994). Implicit and explicit memory for compound words. *Memory & Cognition*, **22**, 687-694.
- REINITZ, M. T., WRIGHT, E., & LOFTUS, G. R. (1989). Effects of semantic priming on visual encoding of pictures. *Journal of Experimental Psychology: General*, **118**, 280-297.
- SCHACTER, D. (1994, June). *PET studies of implicit and explicit memory*. Paper presented at the Sixth Annual Meeting of the Memory Disorders Research Society, Cambridge, MA.
- SQUIRE, L. R., OJEMANN, J. G., MIEZIN, F. M., PETERSEN, S. E., VIDEEN, T. O., & RAICHEL, M. E. (1992). Activation of the hippocampus in normal humans: A functional anatomical study of memory. *Proceedings of the National Academy of Sciences*, **89**, 1837-1841.
- STELMACH, L. B., HERDMAN, C. M., & MCNEIL, K. R. (1994). Attentional modulation of visual processes in motion perception. *Journal of Experimental Psychology: Human Perception & Performance*, **20**, 1-14.
- TEICHNER, W. H., & KREBS, M. J. (1974). Laws of visual choice reaction time. *Psychological Review*, **81**, 75-98.
- WARREN, C., & MORTON, J. (1982). The effect of priming on picture recognition. *British Journal of Psychology*, **73**, 117-129.
- WELDON, M. S. (1991). Mechanisms underlying priming on perceptual tests. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **17**, 526-541.

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